

5-2015

Building Information Modeling (BIM): The Untapped Potential for Preservation Documentation and Management

Laura Lee Worrell
Clemson University

Follow this and additional works at: https://tigerprints.clemson.edu/all_theses



Part of the [Historic Preservation and Conservation Commons](#)

Recommended Citation

Worrell, Laura Lee, "Building Information Modeling (BIM): The Untapped Potential for Preservation Documentation and Management" (2015). *All Theses*. 2146.
https://tigerprints.clemson.edu/all_theses/2146

This Thesis is brought to you for free and open access by the Theses at TigerPrints. It has been accepted for inclusion in All Theses by an authorized administrator of TigerPrints. For more information, please contact kokeefe@clemson.edu.

BUILDING INFORMATION MODELING (BIM): THE UNTAPPED POTENTIAL
FOR PRESERVATION DOCUMENTATION AND MANAGEMENT

A Thesis
Presented to
the Graduate School of
Clemson University

In Partial Fulfillment
of the Requirements for the Degree
Master of Science
Historic Preservation

by
Laura Lee Worrell
May 2015

Accepted by:
Amalia Leifeste, Committee Chair
Carter L. Hudgins
Craig M. Bennett, Jr.

ABSTRACT

The preservation field has few software programs specifically created to store historic and management documentation. Some programs and techniques are utilized in combination to aid in the management and documentation process of historic resources that include, laser scanning, AutoDesk AutoCAD programs, Rhino 3D, photogrammetry, geographic information system, and even Microsoft Excel. This thesis examines the applicability of the Architectural, Engineering, and Construction (AEC) industry's Building Information Modeling (BIM) to create a three dimensional user interface for tracking and storing historic and management documentation. The case study performed for this thesis employs the Nathaniel Russell House owned by the Historic Charleston Foundation (HCF) located in Charleston, South Carolina. A house museum best tests BIM's potential application in the field of historic preservation because there is a long time-view on the recording and management of such properties. A 3D model constructed in Autodesk Revit shows the Russell House's structural evolutions through time. The 3D model created in Revit is input into Autodesk NavisWorks to link micro-information. The micro-information links to its associated 3D model components. Once complete, preservation industry professionals test the ease of navigation and object data information gathering. The case-study shows both the promise and the current challenges faced with BIM's application for the preservation field.

DEDICATION

This thesis is dedicated in loving memory to Mommom, and in honor of my loving and supportive family Mom, Daddy, and Ashley: to all the history-enriched family vacations.

ACKNOWLEDGMENTS

First and foremost, I must thank my family for their love, support, guidance, and understanding, always. Mom, I owe my future profession and my greatest passion to you; with your historic themed vacation planning every summer (yes, even the anticlimactic Plymouth Rock detour) and introducing me to a historic preservationist when I was 16. Dad, I owe my skills and knowledge to you; thank you for always being patient even when I was too young to be allowed to use a hammer and your willingness to share with me your vast amount of knowledge. Ashley, I owe my drive to you; thank you for being an amazing role model and giving me the helping hand I often need.

I would like to thank the Virginia Tech Building Construction Undergraduate program and faculty. The knowledge and guidance you provided was more beneficial to me and my career in historic preservation than I could ever have imagined.

A huge thank you to my friends, family, and classmates during this stressful and exciting time. Elizabeth, thank you for being my source of procrastination and my cheerleader during this process. B, without you and George, I would have surely lost my senses. Thank you for your understanding and for being my rock.

This thesis and its topic would not have been conceivable without Amalia Liefeste. Thank you for listening from the first day of classes to the last and for often decoding my thoughts. Thank you to my additional readers Carter L. Hudgins, Craig Bennett, and Ashley Wilson for your enthusiasm and belief in my topic. Whole Building Systems, thank you for taking me under your wing and providing access to your knowledge and resources. Thank you to the work of Glenn Keyes Architects and Orlando

ACKNOWLEDGMENTS (Continued)

Ridout, V, and Willie Graham for the architectural plans provided in the Nathaniel Russell House Historic Structures Report, Volume I.

Lastly, a **grand** thank you to the Historic Charleston Foundation for the subject and documentation access to the Nathaniel Russell House. Will Hamilton, Katherine Pemberton, April Wood, Karen Emmons, and Michelle Palmore: Your excitement, expertise, and time contributions made this thesis possible and I am forever grateful.

TABLE OF CONTENTS

	Page
TITLE PAGE	i
ABSTRACT.....	ii
DEDICATION	iii
ACKNOWLEDGMENTS	iv
LIST OF IMAGES.....	viii
CHAPTER	
I. INTRODUCTION	1
II. DOCUMENTATION AND RECORDS MANAGEMENT PRACTICES...	8
The Evolution of Documentation Methods.....	10
The Evolution of Records Management	21
HBIM Example Case Studies	28
Conclusion	31
III. METHODOLOGY	32
Research	32
Archival and Management Documentation	34
Revit Working Model	37
Accessing Documentation through Navisworks	59
IV. CASE STUDY: THE NATHANIEL RUSSELL HOUSE	67
Introduction.....	67
History.....	70
Architectural Changes – Period I to Period VII.....	77
Methodology	90
Case Study Findings	96
Analysis and Conclusion.....	107
V. CONCLUSION.....	111

Table of Contents (Continued)

	Page
APPENDICES	120
A: Industry Profession Questionnaire.....	121
B: Model Testing Agenda.....	122
C: Architectural Drawings of the Nathaniel Russell House: Period I – Period VII.....	123
REFERENCES	156

LIST OF IMAGES

Image	Page
2.1 Example HABS drawing ca. 1934	10
2.2 Autodesk AutoCAD screen shot of the Aiken-Rhett House ca. 2013	14
2.3 Point cloud screen shot of Ellis Island hospital ca. 2014.....	16
3.1 Linking Autodesk AutoCAD files to Revit screen shot.....	40
3.2 Screen shot of Revit with linked AutoCAD files in 3D.....	41
3.3 Revit phasing creation screen shot.....	43
3.4 Revit wall type assembly dialogue box	44
3.5 Revit type properties dialogue box	46
3.6 Revit family type finish edit mode screen shot.....	50
3.7 Revit family type creation templates	53
3.8 Revit family type creation work windows	54
3.9 Revit family type parameters dialogue box	55
3.10 Completed Revit model of the Nathaniel Russell House.....	57
3.11 Autodesk Navisworks merge files dialogue box	60
3.12 Navisworks selection tree	61
3.13 Navisworks find items and timeliner	62
4.1 Nathaniel Russell House c. 1940	67
4.2 Charles Towne Grande Modell.....	69
4.3 Nathaniel Russell House Period I Revit model.....	72
4.4 Nathaniel Russell House third floor east bed chamber	73

List of Images (Continued)

Image	Page
4.5 Nathaniel Russell House Period I – south elevation	77
4.6 Nathaniel Russell House Period I – first floor plan	77
4.7 Nathaniel Russell House exterior east elevation.....	78
4.8 Nathaniel Russell House exterior south elevation	78
4.9 Nathaniel Russell House balustrade detail.....	78
4.10 Nathaniel Russell House first floor east entrance	79
4.11 Nathaniel Russell House grand staircase	80
4.12 Nathaniel Russell House first floor dining room	80
4.13 Nathaniel Russell House Period II Revit rendering	81
4.14 Nathaniel Russell House original servant staircase	82
4.15 Nathaniel Russell House original servant staircase	86
4.16 Nathaniel Russell House 1950’s servant staircase replacement	86
4.17 Nathaniel Russell House first floor west room blind windows	88
4.18 Nathaniel Russell House gift shop.....	88

CHAPTER ONE

INTRODUCTION

The inheritance of poorly or inconsistently managed historic and maintenance documentation plagues many preservationist. A new employee's predecessor took all the knowledge they possessed on the resource during their tenure with them when they retired. He or she worked in the position for thirty years and had no reason to keep adequate documents; they mentally took notes of all work performed and history discovered. During the first week of starting a new job, perhaps a new preservationist discovered records from ten years ago are moldy and unrecoverable in the storage closet. No one knew the air handler unit had been dripping condensation on them for the past three years. Or perhaps a historic preservation organization digitized all records on a new computer system five years ago but no updates have been performed since. These scenarios and others similar to them occur consistently with organizational employee turnover. Anything from human error, neglect, happenstance, or to uncontrollable disasters are the causes behind improper records management. The Nathaniel Russell House museum in Charleston, South Carolina is a perfect example of a resource that requires properly maintained documentation and is cared for by a the dedicated party, interested in exploring a Building Information Modeling (BIM) records management system.

No matter the cause behind records management issues, they exist and are sadly more prevalent than anyone would like. The United States' historic resources are meant to be preserved for the enjoyment and education of future generations. Inadequate records

complicate and hinder preservation efforts. Time and money are often lost in search of information that previously existed but has been lost or misplaced due to unmaintained records. Such situations result in the waste of valuable resources that could be better deployed to sustain or improve a historic resource such as the Nathaniel Russell House museum.

The management of records and documentation is seldom the highlight of a job, but without it effectively performing the job can be difficult - especially when it comes to a historic resource. Historically, records were kept in hard copy paper formats. With the introduction of personal computers in the 1980s many organizations moved to both hard paper and “soft” digital records. Today, industry specific management and record software helps many organizations more effectively track and maintain documentation. Some businesses create their own documentation guidelines and standards instead of purchasing a records management software. Both are viable options and can work effectively or not depending on the maintenance of the records input.

An organizational commitment is necessary to ensure the continual maintenance of existing records and the consistent input of new documents for an effective records management system. Those in the preservation field know that without adequate historic and maintenance documentation, it is hard, if not impossible, to make appropriate decisions for a historic resource. The preservation field is sometimes characterized as being opposed to change and that includes utilizing new technology. However, many examples exist to refute these assumptions.

Interest in three-dimensional (3D) technologies is gaining momentum in the field of preservation, especially since 2007-2008. Preservationists are challenging the process of documentation and employing new technologies to expand what can be documented. The imagery and assets offered by these 3D technologies is making preservationists demand access to funds and personnel to explore these processes. 3D Laser scanning is a prime example of new documentation technology within the preservation world.

The speed of documentation and the detailed imagery that laser scanning provides for historic resource owners is captivating. As preservationists are learning and experiencing the potential capabilities behind this technology and others, they are seeking to expand the technologies' applications to historic preservation. The next stage in this documentation process capability is the incorporation of records management. The integration of the imagery documentation and a multifaceted user interface to include data can revolutionize the way historic resources are operated, maintained, and experienced.

The use of BIM is a proven effective tool for the design, engineering, and construction industry. BIM is the process used to generate and manage the physical and functional characteristic of places in a digital format. BIM allows owners, designers, engineers, and builders to coordinate all stages of construction resulting in time and cost savings. With the introduction of laser scanning, BIM is being considered for preservation purposes. BIM contains the potential to create an all-encompassing 3D user interface for historic resource and building owners. The platform software that operates the BIM model has the capability for additive software. The additive plug-in applications

that are available in the market are comparable to a smart phone's downloadable apps that expand what the phone can do. One example includes tools for curation decisions and visual aids for public interest and education in the form of fly-through videos or interactive platforms. Restoration or additions can be incorporated into the model to show investors schedules, costs, and visual appearance of new work to be performed before it is actually done. Much as the Geospatial Information System (GIS) was useful for analyzing large areas, BIM models can aid historic resource stakeholders in decision making and analysis tasks. The BIM model that includes historic and maintenance information creates a holistic repository to better and more effectively care for the historic resource.

Interest in documentation of historic resources has grown in part because of the curation and educational potentials of laser scanning. Finding that same enthusiasm for proper records management is much harder. This thesis will explore the potential of BIM as an effective records management user interface for historic resource stakeholders. A case study to develop an effective work flow for producing a model and accessing the records in the BIM interface is a first step toward developing BIM best-practice procedures for the preservation community. A historic house museum was chosen as the ideal case study subject. These buildings require the long-term retention of documentation and maintenance to guide their interpretation and preservation and have owners invested in ensuring their long-range future.

The first chapter introduces the evolution of documentation and management tools in the preservation field. The first major instance of documenting historic resources

began in 1934 through hand measurements methods and photography. With the need to care for and document massive amounts of land, the introduction of Geographic Information System (GIS) and photogrammetry helped to accomplish this feat quickly and with minimal error. Personal computers and computer-aided design (CAD) moved the hand-drawn documentation process to an electronic format creating faster and more accurate 2-dimensional (2D) documentation drawings. Now BIM models can act as the 3D repository for previous historic and maintenance records created from Historic Structures Reports (HSR) in addition to hard paper and soft digital copies of records with the fourth dimension of time included. With the inclusion of BIM into already existing GIS models, some resource documentation will not need to be recreated but instead may become seamlessly integrated. Furthermore, other newer softwares, such as Computerized Maintenance Management Systems (CMMS) bring in a new useful resource to the BIM models. CMMS programs help maintenance personnel track and maintain operations in a digital database. Two case studies from 2011 and 2013 provide additional examples of other methods to accomplish a Historic Building Information Modeling (HBIM) integration of historic and management documentation into BIM for historic resources. With this background information and previous experience, a workflow method for creating a new HBIM application is developed.

The third chapter describes the HBIM creation methodology. A survey presented to various historic professionals helped to determine current practices for documentation and maintenance methods in the field. Organizing the case study subject documentation into an excel document helps to prepare for Revit modeling. This thesis does not intend to

address the methods of capturing field measurements of a structure but instead the digital platform to record and store management records in a 3D representation of the building. The methods for modeling a subject in Autodesk Revit provides a work flow process to model the building in BIM. The tasks required to transfer the model into Autodesk Navisworks and attach/link records to the model's objects completes the methodology for creating the HBIM user-interface platform. The final step to discover the application's success or failure includes the development of testing scenarios.

Chapter 4 describes the case study performed in compliance with the methodology set forth in chapter 3. The history and architectural changes of the house establishes the periods of significance modeled in Revit. An abbreviated work flow methodology provides the software and steps used to accomplish the HBIM model. Successes and issues discovered during the work flow process and testing phase give insight into the case study's success and challenges, reflecting how well suited BIM is to historic preservation applications.

The final chapter of this thesis develops conclusions on potential use of HBIM in the preservation field. The conclusions are informed by case studies as well as the method, process, and procedures developed in this thesis. Great authority is given to the results found during the testing phase. Without the investment of the preservation field as prospective HBIM users, development of the software toward historic preservation end goals is not possible. Many different work flow methods are possible to create a HBIM for historic and maintenance documentation user interfaces. The methods chosen for this

thesis in comparison to previous explored methods can help inform best-practices in the development and use of BIM for historic resources.

CHAPTER TWO

DOCUMENTATION AND RECORDS MANAGEMENT PRACTICES

The care and management practices for historic resources vary depending on the mission of the property or resource. For example, two of the properties owned by Historic Charleston Foundation on the historic downtown Charleston peninsula are treated completely differently. The Nathaniel Russell House operates under the restoration method of preservation. This practice restores the house to the appearance of when its namesake resided in the house. On the other end of the preservation spectrum, the Aiken-Rhett House is operated under the “preserve as found” conservation methodology which elects to not restore the resource. Instead this practice attempts to stall deterioration as much as possible while keeping the resource in the same state as when it was acquired. The over-arching purpose of both preservation practices is to provide a historic resource for the education and enjoyment of future generations; an ideology that remains central to the preservation field, and the mission of the National Park Service (NPS) since its inception in 1916.

Today, the NPS is the guiding authority for the treatment of historic resources. The organization provides the preservation field and the public with basic guidelines and at-minimum standards for the treatment of the nation’s historic resources. This chapter does not attempt to explain the treatment and management methodologies but instead focuses on the tools that help document and track the history and management of our nation’s historic resources and help guide the decisions made surrounding their care. Through changing preservation best-practice theories and personnel changes it is

imperative to maintain holistic and accurate documentation of the resource and work performed to maintain its integrity. This knowledge helps to make better decisions for the resource as needs or problems arise.

One example of a time of critical record documentation and maintenance occurred due to a natural disaster. After the damage incurred by Charleston's 1989 Hurricane Hugo, repairs to the Nathaniel Russell House were carried out responsibly because of proper historic and maintenance management documentation. When the Aiken-Rhett House faced the choice of whether or not to restore the exterior stucco to help conserve the integrity of the structure, an educated decision could be made because proper historic and maintenance documentation were available to guide the decision. The importance of documentation management can result in the success or failure of maintaining a historic resource.

The following narrative discusses, chronologically, the evolving options for documentation and management systems available to the preservation community. Recent case studies examples demonstrate attempts to revolutionize documentation and management practices.

2.1 The Evolution of Documentation Methods

The birth of historic preservation began with the purchase and conservation of George Washington's Mount Vernon homestead in 1853. Sixty-three years later in 1916, the National Park Service (NPS) was founded to serve as the management agency for overseeing scenic and scientific values of western lands considered to be economically useless. At this point in preservation history, documentation was not a priority, the protection of federally owned resources from further decay and disappearance was the key focus. The most important and vast documentation initiative of the nation's historic resources did not begin until late 1933, eight decades after the purchase of Mount Vernon and seventeen years after the founding of the NPS.

Charles Peterson proposed the implementation of Historic American Buildings Survey (HABS) as a means to help employ out-of-work architects, draftsmen, and photographers during the years of the Great Depression as a part of Roosevelt's New Deal agenda. Peterson recognized the quickly diminishing stock of historic structures and resources around the nation due to the poor economy, natural disasters, and "the demolition and alterations caused by real estate 'improvements' [that] form an inexorable tide of destruction destined to wipe out the great majority of the buildings which knew the beginning and first flourish of the nation."¹ HABS formed a cooperative between the NPS, the American Institute of Architects (AIA), and the Library of Congress (LoC);

¹ Charles E. Peterson, Memorandum, November 13, 1933, handwritten memo, NARA RG 515, HABS/HAER. As quoted from John H. Sprinkle, "An Orderly, Balanced, and Comprehensive Panorama," in *Crafting Preservation Criteria: The National Register of Historic Places and American Historic Preservation* (New York, NY: Routledge, 2014), pg. 30.

NPS identified important resources, the AIA documented the resources, and the LoC preserved the permanent records.²

By the end of the first year, 1934, HABS employees documented 850 different historic and cultural resources. Documentation methods at this time included hand measurements, hand drafting, and photography. Field measurements and drafting of the resources was time consuming. The number of identified resources was growing daily and many had limited time before demolition or decay took hold, rendering them unrecognizable. HABS created standards in 1935 to help insure consistency and accuracy of the information from field work and the accuracy and graphic character of the final measured drawings and photograph documentation products. *Image 2.1* provides an early example of HABS hand measured and drawn documentation.

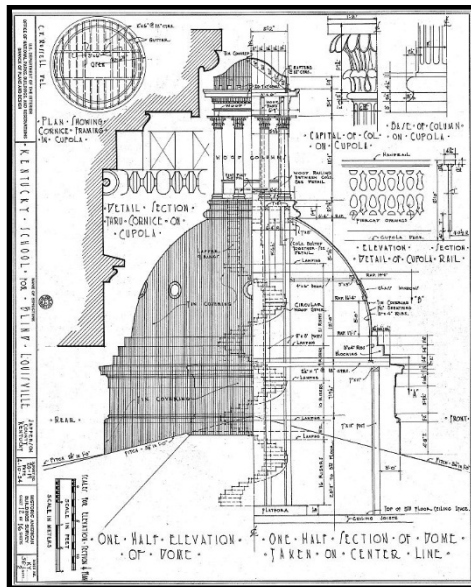


Image 2.1 The above image is a HABS drawings created in 1934 for the Kentucky School for the Blind in Louisville, Jefferson County, Kentucky. An exemplary representation of the details achieved from hand measurements and hand drafting. Image courtesy of 1867 Frankfort Avenue. Sheet 12 of 16, Kentucky School for the Blind, c. 1867. HABS Drawings, 1934. (Library of Congress, Prints and Photographs Division HABS KY, 56-LOUVI, 2), <http://www.loc.gov/pictures/item/ky0070.sheet.00012a/>.

² John H. Sprinkle, "An Orderly, Balanced, and Comprehensive Panorama," 2014, pg. 30.

The documentation of historic resources has two components, field work and architectural drawings. Documentation of architectural and landscape resources remained heavily reliant on hand measurements with photography to complete field work for many decades. Hand drafting techniques built from the field work to create drawings of the resource in accordance with HABS standards. Later, the development of photogrammetry and Geographic Information Systems (GIS) were included as additional field capturing techniques. They helped produce documentation more quickly and accurately than traditional hand techniques, primarily for large geospatial resources. The field work then could be hand or computer drafted.

Photogrammetry is the science of making measurements from photographs. The creation of photogrammetry gave photographs, which visually documented overall appearance, spatial connectivity, and details, an additional role. Photogrammetry developments began around 1850 for map making purposes using plane table photogrammetry. Around the turn of the 20th century photogrammetry production methods moved to an analog system to produce maps.³ By 1960, with the introduction of computers, analytical photogrammetry methods developed. Photogrammetry at this point in its evolution achieved great accuracy in a shorter period of time with reduced human error compared to hand measurement methods. However, the cost of the equipment to produce the photogrammetric imagery was astronomical and thus prevented wide spread adoption of this method.⁴

³ Bon DeWitt and Benjamin Wilkinson, "Introduction," in *Elements of Photogrammetry with Application in GIS*, by Paul Wolf, Fourth ed. (McGraw-Hill Professional, 2014).

⁴ George C. Skarmas, "From HABS to BIM: Personal Experiences, Thoughts, and Reflections," *APT Bulletin* 41, no. 4 (2010): pg. 48, accessed September 22, 2014, <http://www.jstor.org/stable/41000038>.

By 1986, Uki Helava developed digital photogrammetry at General Dynamics for the Defense Mapping Agency, now called National Imagery and Mapping Agency (NIMA).⁵ The automation of photogrammetric practice improves accuracy of documentation. Today, in addition to mapping, photogrammetry is a viable method and tool for the conservation and preservation field. Photogrammetry captures data in less time than traditional hand measurement methods for both small and large resources and allows for the recordation of non-orthographic objects, such as sculptures.⁶

Photogrammetry in its beginnings was for mapping purposes and was then eventually utilized in conjunction with the development of the geographic information system (GIS) which had its beginnings around 1968. GIS is a computer based system that links geospatial data with maps. By capturing, storing, and displaying data in layers related to locations on Earth's surface, data can more easily be seen, analyzed, and understood based on patterns and relationships to one another. The development and first application use of GIS is attributed to the Canada Geographic Information System that occurred in the 1960s.⁷ Along with private entities, GIS in conjunction with global position system (GPS) is now utilized largely by the federal, state, and local governments of the United States to store and analyze data for many different capacities. Some of its uses include tracking endangered species on public lands or utilizing accident data to determine traffic improvement opportunities. The use and integration of GIS within the

⁵ T. Schenk, *Digital Photogrammetry*, report (Laurelville,, OH: TerraScience, 1999), pg. 428.

⁶ Georgia O'Keeffe Museum, *Applications of Digital Photogrammetric Methods for Preservation Documentation of Historic Homes*, report (Natchitoches, LA: National Center for Preservation Technology and Training, 2012), pg. 4.

⁷ Roger Tomlinson and M.A.G. Toomey, "GIS and LIS in Canada," in Gerald McGrath and L. M. Sebert, "Chapter 15," in *Mapping a Northern Land: The Survey of Canada, 1947-1994* (Montreal: McGill-Queen's University Press, 1999), pg. 462.

Park Service that began in the late 1980s and was due to the large amount of land that is under the stewardship of the NPS. The NPS uses GIS specifically to store and document its maintenance records. This will be further discussed in the management methods section of this chapter.

GIS and photogrammetry were both initially utilized for documentation of larger geospatial resources. Later, both photogrammetry and GIS were applied to smaller areas, structures, and even documentation of individual elements. The main catalyst that led to creating faster, more accurate documentation of these smaller resources, however, was the introduction of two-dimensional (2D) Computer-Aided Drafting (CAD). CAD is a type of digital software that uses vector based geometry to create drawings. This tool was instrumental in advancing the drafting of finished measured drawings not the field recording side of the documentation process. In the early 1970s the introduction of computers led to the development of CAD but the technology was not widely used until the mid to late 1980s, once lower cost and higher efficiency in personally owned computers had spread. Through the 1980s and beyond, the decrease in the proprietary CAD programs' costs helped to make the software more accessible.⁸

CAD allows users to employ computers for the production of architectural and engineering drawings of structures, producing faster and more accurate end documents. Today, Autodesk Inc. and Parametric Technology Corporation are the leading proprietary systems that provide this service. AutoCAD, a drafting software developed by Autodesk,

⁸ Skarneas, George C. November 2-3, 2009. "From HABS to BIM: Personal Experiences, Thoughts, and Reflections." *APT Bulletin*, Vol. 41, *Special Issue on Documentation*. Los Angeles: Association for Preservation Technology International (APT). 47-53.

it was the first and is the most widely used CAD program on the market worldwide. CAD developed for implementation in the design and new construction field.⁹ The adoption of CAD in the preservation field was slow. It was not until 2000 that the NPS and HABS amended the Secretary of the Interior's Standards and Guidelines to include standards for recording historic sites and structures using CAD software.¹⁰ HABS sets the minimal standards for which all historic resources abide by. Their guidelines not only set the standard but also reflect influences from preservation practitioners. *Image 2.2* provides an example of modern CAD software, Autodesk's AutoCAD.

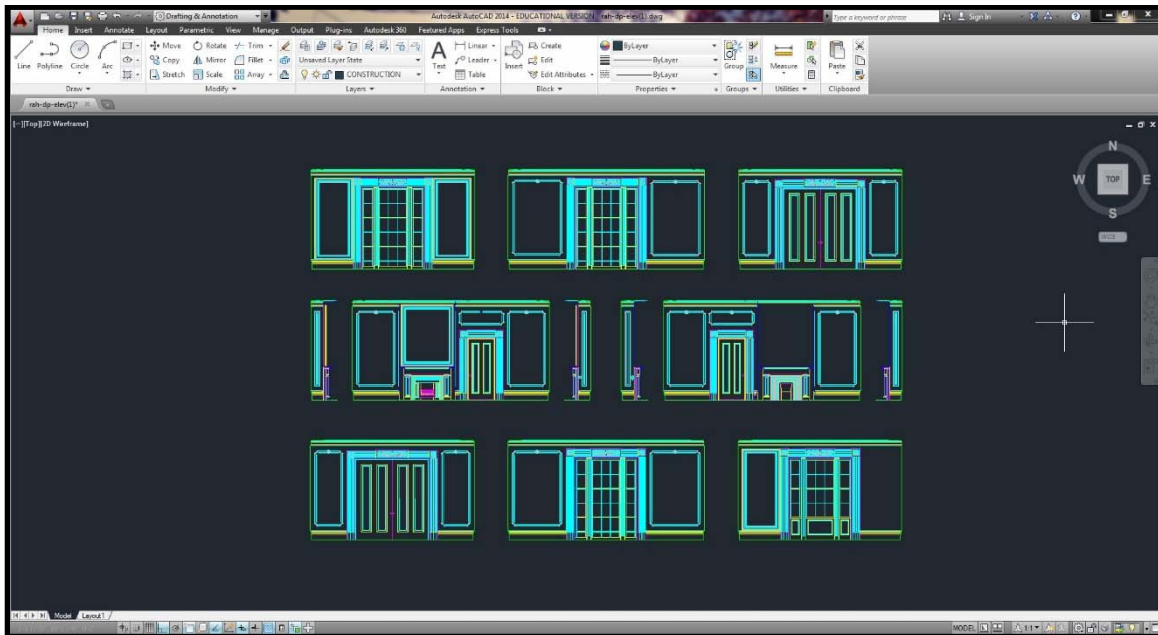


Image 2.2 The image above shows AutoCAD, a modern software version, used to create elevation drawings for the Aiken-Rhett House located in Charleston, South Carolina done by HABS in 2013. Photo courtesy of Laura Lee Worrell. Drawings courtesy of Sanders, Sarah, Mark Schara, and Laura L. Worrell. "Aiken-Rhett House Elevations" Digital drawings. December 2013.

⁹ Skarmas, George C. November 2-3, 2009. "From HABS to BIM: Personal Experiences, Thoughts, and Reflections." *APT Bulletin*, Vol. 41, Special Issue on Documentation. Los Angeles: Association for Preservation Technology International (APT). 47-53.

¹⁰ United States. National Park Service, "Secretary's Standards--Architectural and Engineering Documentation," National Parks Service, section goes here, accessed February 24, 2015, http://www.nps.gov/history/local-law/arch_stnds_6.htm.

The next evolution in documentation tools is Building Information Modeling (BIM). The term Building Information Modeling (BIM), coined by the design and construction fields over 20 years ago, describes the next phase in CAD development. BIM takes three-dimensional (3D) CAD objects tied to a database and associates them with time attributes for a 'four-dimensional' building model. Initially driven by the architectural field, contractors now drive the use of BIM as of 2012. The use of BIM within the design and construction industry has increased from 28% in 2007 to 71% in 2012.¹¹ With the rise in popularity and use of BIM for design and new construction purposes, there are attempts to create a Historic Building Information Modeling (HBIM) specific application to further the field of preservation documentation. Discussed later in this chapter, example HBIM case studies are explored in this thesis. These scenarios show that the best practices for BIM creation are still being developed and perfected.

BIM addresses the measured drawing and model production of resource documentation. A later useful additive tool to BIM and documentation is laser scanning which is a technology development related to field capture and recording.¹² Laser scanning technology was developed to document resources three-dimensionally. Laser scanning first developed in the 1960's but was largely limited until technological advancements after 1985.¹³ Modern laser scanners come in a variety of models that have

¹¹ McGraw-Hill Construction, *The Business Value of BIM in North America: Multi-Year Trend Analysis and User Ratings (2007-2012)*, report (2012), pg. 4.

¹² Laser scanning and its related buzz word, "the point cloud," is a technology that addresses the field recording and documentation step of the process.

¹³ Dr. Mostafa Abdel-Bary Ebrahim, *3D Laser Scanners: History, Applications, and Future*, Civil Engineering Department, Assiut University, Research Gate, October 2011, pg. 1, http://www.researchgate.net/profile/Mostafa_Ebrahim/publication/267037683_3D_LASER_SCANNERS_HISTORY_APPLICATIONS_AND_FUTURE/links/5442bdf10cf2e6f0c0f93727.pdf.

varying optimal scan ranges, from miles to millimeters. The final product of a laser scanner is a 3D point cloud. Points are created through calculations in the scanner that determine the rate at which it took the laser to reach the surface of an object. The points are assigned x, y, and z coordinates which creates a dense cloud of individual points in 3D recreating, or also called reconstructing, the object's surface that was scanned.¹⁴ *Image 2.3* provides a screen shot image of the product of laser scanning, the point cloud.¹⁵ Color data can also be attached to individual points through a high dynamic range pano-photo texture mapping process that utilizes DSRL camera equipment.¹⁶

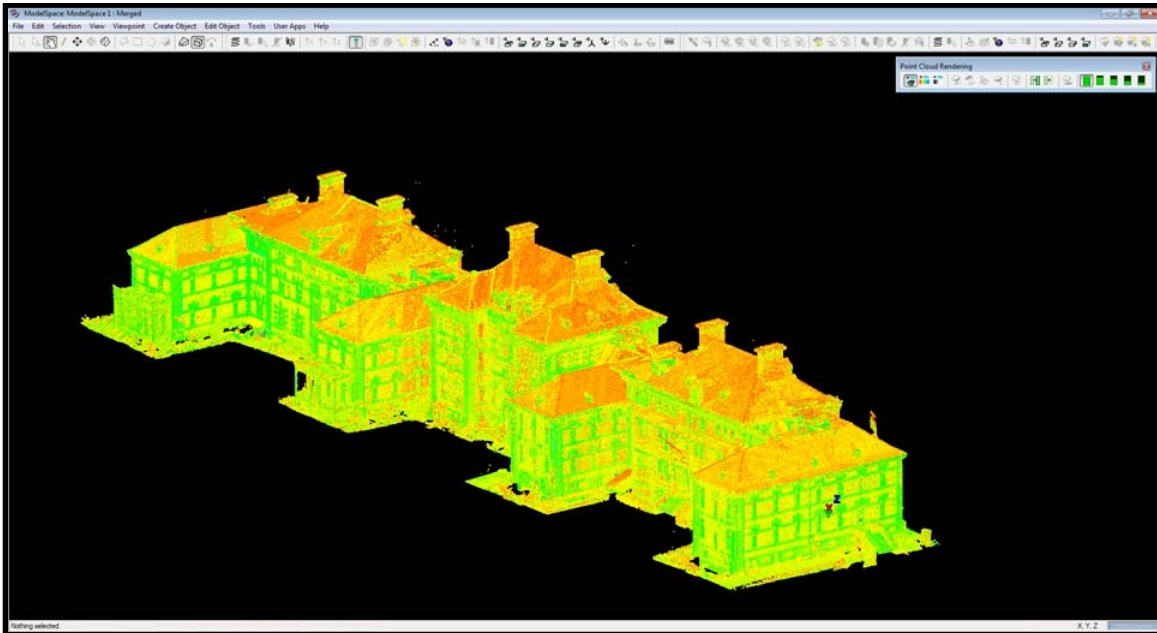


Image 2.3 The image above shows a screen shot of the point cloud created from laser scanning performed at Ellis Island Hospital in New Jersey. Photo courtesy of Laura Lee Worrell. Laser scanning and point cloud courtesy of Paul Davidson and Daniel De Sousa, HABS, 2014.

¹⁴ Dr. Mostafa Abdel-Bary Ebrahim, *3D Laser Scanners*, pg. 3.

¹⁵ Visit www.Cyark.org to navigate and see interactive “point clouds” produced from laser scanning of various world heritage sites.

¹⁶ A high resolution photograph with a fish lens is taken in the exact same location as the laser scan. Picture distortion is rectified and the image is mapped onto the point cloud within computer software. A realistic 3D model of the resource is created using this method. Resolution of the 3D model can vary depending on the laser scan resolution versus the photograph resolution.

In 2012, the National Center for Preservation Technology and Training (NCPTT) held a *3D Digital Documentation Summit*. The Summit brought members of the preservation community together to discuss digital forms of documentation, one in particular being laser scanning. HABS employees spoke on the advantages and disadvantages of this tool for documenting historic resources. The overall understanding of laser scanning during this summit can be described as one tool among many for capturing and documentation purposes and is best when combined with other documentation methods.

HABS found that time and money saved in the field documenting with laser scanning was often offset during in-office post-processing of the digital data. Small intricate details remain best documented using hand measurements. In comparison, holistic building envelopes, high elevations, and inaccessible areas and elements are best documented with laser scanners in conjunction with photographs. This paring of techniques saves on time and achieves accuracy.¹⁷ Another set of hindrances to laser scanning is the extensive knowledge needed to produce a usable and working 3D point cloud model and the high cost of the multiple proprietary softwares needed. Laser scanning is a beneficial tool utilized in conjunction with other documentation methods as advocated by HABS and the NPS to develop archival 2D drawings and to produce interpretive tools.¹⁸ The use of laser scanning in conjunction with BIM is occurring within large scale renovation of existing buildings. The processing capacities of

¹⁷ Paul Davidson and Dana Lockett, *Assessing the Value of Laser Scan Data*, proceedings of 3D Digital Documentation Summit, Presidio, San Francisco, CA, doi:<http://ncptt.nps.gov/blog/documentation-to-the-secretary-of-the-interiors-standards-assessing-the-value-of-laser-scan-data/>.

¹⁸ CyArk.org is a non-profit organization founded in 2003 that utilizes 3D laser scanning to document heritage sites from around the world and makes the accessible to the public for free through the internet.

computers are not yet sufficient enough to properly manage the large size of BIM and laser scanning files of big, complex projects. Because these two technologies are dependent on the other, many in the field anticipate that in the next few years these two technologies will meet to create a better, more efficient tool working as one.

This thesis intends to explore the application of BIM for documentation and management of historic resources. The scope of this thesis does not, however, intend to critically investigate all methods of data retrieval for BIM creation. It is important to understand the different available options for field recording: hand measurements, Geographic Information Systems (GIS) in conjunction with Global Positioning System (GPS), photogrammetry, and laser scanning. Hand measurements were the first, and arguably still the most accurate for certain architectural elements, overall method for documentation. The use of measuring tapes, poles, wheels, and even laser distance measurers, accurately give large and small distances. Molding profile combs and photographs helps to document fine and ornate architectural details. This method is the most timely and error prone, however, but it can capture small and ornate detailing not obtainable by other documentation methods. GIS is still mainly only being utilized for the recording of large geospatial areas. The resurgence of photogrammetry because of digital cameras and lower cost proprietary software has resulted in the documentation of large areas and small elements with distortion corrected images. Improvement in methods and software have helped to create a more accurate and speedy documentation process option in photogrammetry. Lastly, laser scanning has radically changed the thinking and processes for documenting historic resources.

BIM, and HBIM attempts, can utilize the variety of methods mentioned previously as input in order to produce the final documentation model. These methods are vast and can vary greatly, and can be used in combination with one another. For example, HABS utilizes the combination of hand measurements, laser scanning, photogrammetry, and Geographic Information Systems (GIS) in conjunction with global positioning system (GPS), to produce AutoCAD 2D documentation plans of a resource. Some projects may utilize all types of measuring methods, while other projects only require the use of one or more methods. These same documenting methods are the foundation for BIM model development. Due to the restrictions set by the Library of Congress for archival requirements of stored media, digital files are not yet accepted as a viable documentation method and HABS as yet to fully address digital documentation in its guidelines.¹⁹ The storage life of digital files are not predictable and the size of some of the individual files are too large, especially point cloud files produced from laser scanning. Therefore, HABS does not yet find it viable to translate point cloud and other documentation methods into 3D BIM models. In fact, HABS only supplies the Library of Congress with printed 2D plans.

¹⁹ Catherine C. Lavoie, "The Role of HABS in the Field of Architectural Documentation," *APT Bulletin: Special Issue on Documentation*, 4th ser., 41 (2010): pg. #21-22, <http://www.jstor.org/stable/41000033>. Paul Davidson and Dana Lockett, *Assessing the Value of Laser Scan Data*, 2012.

2.2 The Evolution of Management Documentation

Shortly after the creation of HABS, Charles E. Peterson's produced a document of the Moore House, a historically significant resource at the Colonial National History Park, after its restoration. While not published by NPS until 1935, his work is unanimously acknowledged as the first historic structure report (HSR) capturing in detail a structure for archival documentation and historical purposes. NPS found this document so pivotal in the documentation and management of its structures, they continued to produce these reports over the next few decades for archival purposes. In 1957, an organization-wide standard format was developed for the reports. Later, in 1963, the *Historic and Prehistoric Structures Handbook* was released as a more comprehensive guidebook for conducting and producing the reports. The HSR best practices continued to be modified and changed in 1971 and again in 1979.

Published in 1980, the National Park Service released its *Director's Order #28*. The *Cultural Resource Management Guideline* has been revised since its first publication but is still in use today as the primary means and guidelines for producing the HSR. All the modifications and revisions of the HSR are intended to streamline and provide important maintenance information such as budget and scheduling, history and existing conditions, and primary planning documents for decision-making to managers of the resources.²⁰ The HSR's development has resulted in a document that aims to include all historical documentation and structural information about the changes accrued overtime

²⁰ Deborah Slaton, "Preservation Brief 43: The Preparation and Use of Historic Structure Reports," National Parks Service, April 2005, accessed March 03, 2015, <http://www.nps.gov/tps/how-to-preserve/briefs/43-historic-structure-reports.htm>.
Sprinkle, Jr., John H. 2014. "Crafting Preservation Criteria." 6-32. New York, NY: Routledge.

to the historic resource. The HSR was the first standardized document meant to be a management tool for historic resources.

Management documentation remained reliant on hard-paper copies and personnel knowledge until the implementation of personal computers in the early 1980's.²¹ Digital copies of documents were still slow to be incorporated at this stage because of the fast evolving methods of data storage and reliability of the computers. Even today, organizations still keep both hard paper and soft digital copies of documents. The archival life of hard copies is understood and known while that of digital data is still being determined. As mentioned previously, the Library of Congress is still working on archival guidelines and requirements for digital data.²² Even with both forms of archival data, the usefulness of all types of documentation is dependent on the records management of the sources. Reports and documents are often lost or forgotten, resulting in wasted resources, time, and money.

The application of GIS has, in the past three decades, intended to improve the data management practices of the NPS. Because GIS is able to incorporate different types of documentation in one platform, it is used as a maintenance and tracking repository for many different entities. NPS's GIS system is one example of the application's use. Each branch and region of the United States are largely responsible for their own data collection and GIS system in the NPS. Because there is not one mass GIS repository, it

²¹ Eppich, Rand, and Amel Chabbi, *Recording, Documenting, and Information Management for the Conservation of Heritage Places: Guiding Principles*, publication, 2007 ed. (Los Angeles, CA: Getty Conservation Institute, 2007), pg. 86, http://hdl.handle.net/10020/gci_pubs/recordim_vol2.

²² Anne Mason, *Archive of Digital Data for HABS, HAER, and HALS*, proceedings of 3D Digital Documentation Summit, Presidio, San Francisco, CA, April 2012, <http://ncptt.nps.gov/blog/archive-of-digital-data-for-habs-haer-and-hals/>.

results in the duplication of data costing a lot of unnecessary money and resources. To combat this issue the NPS and Federal Government have invested in methods to help with effective data sharing and information management and archive planning.²³ The implementation and effectiveness of these attempts however, are not seen holistically on the public access front. Many different attempts at accessing a variety of states' GIS web sources lead to non-active web pages or links that re-navigated users to unrelated web pages.²⁴

BIM is another, more recent, tool for management documentation. BIM takes the GIS analysis and tracking capabilities to a higher level. BIM initially aided in the design and construction phase of a building. The designers and contractors could attach schedules and costs to the model's elements. Clash detections could be performed to see what designed elements would interfere with one another in the built environment before construction as a money and time saving advantage. Today, even more BIM applications exist that allow not only the tracking of constructability but also management activities and the cost and scheduling projections of future needs. Facilities Management (FM) tools are now being incorporated in the BIM models to create an ever expanding application platform for management and documentation. Computerized Maintenance Management Systems (CMMS) is an example of an existing FM tool being incorporated

²³ Christina Wright, Joe DeVivo, and Kate Funk, *Information Management and Archiving Plan: Southeast Coast Inventory and Monitoring Network*, report no. NPS/SECN/NRR-2005/062 (Fort Collins, Colorado: U.S. Department of the Interior National Park Service, 2008), pg. 1-16.
Geographic Information Systems: Challenges to Effective Data Sharing, Subcommittee on Technology, Information Policy, Intergovernmental Relations and the Census, Committee on Government Reform, House of Representatives Cong. (2003) (testimony of Linda D. Koontz).

²⁴ These errors may be caused by a breakdown in internet website management and not in the GIS resources themselves.

with BIM. These tools can manage and plan the day-to-day operations and maintenance activities required of a facility or structure.

CMMS's can be tailored for specific facilities or project needs and requirements making them extremely versatile from one industry to the next.²⁵ The implementation of CMMS into the BIM platform has been difficult because of the proprietary software needs and the unknown software restrictions and problems discovered during integration. Construction-Operation Building Information Exchange (COBie) is currently in the process of creating and setting guidelines and a repository for sharing maintenance documentations for the new construction world for use in CMMS's.²⁶ COBie provides resources and example project templates so that industry professionals can conduct trials and in turn provide feedback on successes and problematic issues. These applications are not being developed for the historic resource industry specifically, but case studies that attempt to introduce FM with BIM models for existing buildings are being employed. One such example is available on Autodesk University, Classes on Demand. The case study walks through the workflow of a project that took laser scans of an existing building to create a BIM model for facilities management.²⁷

The trajectory for the historic preservation field is the integration of all the previously discussed documentation and management methods into one platform. The

²⁵ Don Sapp and Dan Eckstein, "Computerized Maintenance Management Systems (CMMS)," Computerized Maintenance Management Systems (CMMS), October 23, 2014, accessed February 22, 2015, <http://www.wbdg.org/om/cmms.php>.

²⁶ Bill East, PhD, PE, F.ASCE, *Construction-Operations Building Information Exchange (COBie)*, report, August 4, 2014, <http://www.wbdg.org/resources/cobie.php>.

²⁷ *FM2589: From Laser Scan to Facilities Management: A Workflow Case Study*, dir. Autodesk University, perf. Aaron Maller, Classes On Demand, 2012, <http://au.autodesk.com/au-online/classes-on-demand/class-catalog/2012/autodesk-revit-for-architects/from-laser-scan-to-facilities-management-a-workflow-case-study>.

vast differences of project requirements, documentation methods, and available proprietary software resources make establishing a standardized best-practice work flow difficult. The problem not only exist between industry and profession cross over needs but differences that may lie within one entity. For example, the NPS is responsible for the management of a wide variety of resources; an individual structure has different documentation and management needs from a National Park that covers thousands of square miles with additional resources within its boundaries.

GIS helped to integrate some of the paper and digital documentation of the NPS into one platform. With the development of CAD, there is great desire to integrate the in-place NPS GIS system with their CAD resources. The GIS resources can now contain accurate 2D and 3D representations of the structures within its layers. The integration of CAD information and the historic data already in the GIS interface that has been used for decades will create an even more useful and productive documentation and management resource for the NPS. Guides and standards to facilitate the merge between CAD and GIS have been developed by the Park Service to help make the process easier for its employees and the public to implement.²⁸ The next logical progression for the NPS is to integrate the GIS with BIM capabilities.

The first quarter of the 2000s is a defining period for BIM. BIM is already recognized in the new construction industry as a major asset. European Parliament recognizes the benefits of BIM so much so that in January of 2014, they adopted a

²⁸ National Park Service Northeast Region GIS and University of Rhode Island Environmental Data Center, *CAD to GIS: A Step-By-Step Guide to Converting.dwg CAD Files to GIS Shapefiles*, report (Boston, Massachusetts: National Park Service, 2005).

directive that calls for all 28 European Member States to encourage, specify, or mandate the use of BIM for all publically funded construction or building projects by 2016. Five nations already require the use of BIM for these types of projects.²⁹ The benefits of BIM and its tools, specifically laser scanning as a field capture technique, is already being noted and established in England. English Heritage, comparable in purpose to the United States National Park Service (NPS), published guidelines for laser scanning of archaeology and architecture back in 2011. By contrast, NPS has yet to even directly address digital documentation methods within its guidelines, as previously mentioned. The European Commission has also funded the Durable Architectural Knowledge (DURAARK) program that is currently “developing methods and tools for the Long-Term Preservation (LTP) of architectural knowledge.”³⁰ DURAARK also intends to establish a repository to preserve 3D models for future reuse and knowledge.

The United States is seeing progress in industry-specific driven applications of BIM, such as in FM, and is setting National BIM Standards, though not for preservation specific applications.³¹ Preservationist are often seen as opposed to change and using technological advancements. The 2014 National Preservation Conference put on by the National Trust for Historic Preservation, a leading non-profit for historic places in the United States, chose for the first time, technology as a theme. In the *Opening Plenary* it was noted that the preservation field needs to embrace and use technology for the

²⁹ Autodesk PR, "European Parliament Directive to Spur BIM Adoption in 28 EU Countries," editorial, *In the Fold*, January 31, 2014, http://inthefold.autodesk.com/in_the_fold/2014/01/european-parliament-directive-to-spur-bim-adoption-in-28-eu-countries.html.

³⁰ European Commission, *DURAARK* (DURAARK, 2015), pg. 1.

³¹ National BIM Standard-United States™ Version 2 (NBIMS-US™) has established BIM standards for the United States. <http://www.nationalbimstandard.org/>

betterment of the preservation cause.³² The following case study analysis is provided to discuss previous HBIM attempts. These cases are considered predecessors to the work undertaken in this thesis. The study of previous methods and research helped to inform the methodology chosen for this thesis's case study.

³² Stephanie Meeks, "TrustLive: Opening Plenary and Preservation TOMORROW" (Past Forward National Preservation Conference, Lucas Theatre, Savannah, GA, November 12, 2014).

2.3 HBIM Example Case Studies

Dublin Institute of Technology

In 2011, the Dublin Institute of Technology published the *Integration of HBIM and 3D GIS for Digital Heritage Modelling*. This paper outlined the implementation work flow to create a BIM product for documentation and management of a historic or “heritage” resource. The process utilized laser scanning and photogrammetry to obtain survey data of the resource. A parametric objects library was built by using embedded scripting languages within the Geometric Descriptive Language (GDL) program, a BIM software. The individual parametric objects built for the library were based on historic architectural manuscripts. GDL uses a set of rules developed to alter the shape definition to comply with varying arrangements and rules of classical building design. For example, if the front façade of a three story building contains five window bays, the rules dictate that all bays are proportionate. After integration with the laser scan and photogrammetry, the user is able to manually alter or move objects to the correct location and size if the assigned “rule” does not meet the actual structures. Once the structure is modeled in 3D, it is placed in the CityGML GIS software. This allows data and information to be linked with the individual geographic locations of objects in the model creating a documentation and management HBIM.³³

The same year as the HBIM process was released, a published case study presented findings on a virtual learning course that utilized the HBIM development from the Dublin Institute of Technology. Four different European conservation sites were used

³³ C. Dore and M. Murphy, "Integration of HBIM and 3D GIS for Digital Heritage Modelling," proceedings of Digital Documentation, Edinburg, Scotland (2012), pg. 22-23, <http://arrow.dit.ie/beschconcon/13/>.

for the study. Varying methods were used for survey data collection. Once collected, the methods for building the HBIM model were done in accordance with the 2011 publication. The evaluation of the HBIM process from the students found that the software platforms were not completely compatible with one another, specifically the point cloud and survey data into the 3D HBIM platform. An additional hindrance to the process included the building of the library objects in the GDL platform. The “basic” coding knowledge required to build the objects tended to be beyond the capabilities of the students in the limited, semester long, time frame given to perform and learn the process.³⁴ The process and application of this HBIM creation is a premiere example of an integrated low-cost option. Reviews from students helped to inform a design and modification of the work flow. To date, no publications of the Dublin Institute of Technology’s updated HBIM method have been found.

George Washington’s Mount Vernon

In 2013, Mount Vernon received a grant from the National Trust for Historic Preservation. A portion of this grant was utilized to develop a HBIM application. Mount Vernon partnered with an architectural firm, Quinn Evans Architects (QEA), and a GIS organization, ESRI (Environmental Systems Research Institute). This HBIM application used laser scanning and supplemental historic architectural drawings to build a 3D model of the structure in Autodesk Revit (performed by QEA). ESRI then took the Revit model and merged it into the online ArcGIS platform. Broader 3D landscape features were also included in the GIS platform. The ArcGIS platform integrates a database associated with

³⁴ A. Chenaux et al., "Combining a Virtual Learning Tool and Onsite Study Visits of Four Conservation Sites in Europe," proceedings of XXIII CIPA Symposium, 2011, <http://arrow.dit.ie/beschconcon/9/>.

the model objects. This HBIM application is described as an “interactive, digital ‘filing cabinet’” customized for Mount Vernon as a repository for the house’s history. The HBIM model will be able to be utilized by academics, researchers, staff, and guests. Future ambition for the HBIM model include representing the whole Mount Vernon estate. The application will continue to be updated to reflect any new information or work performed.³⁵

The internet based GIS platform allows for ease of access and diminishes the concern of data corruption and loss. High up front cost is associated with this HBIM application as industry professionals must be employed to laser scan and model in Revit and GIS. Mount Vernon is currently training its architectural staff to continue building and populating the HBIM. This practice will cut costs and reduce reliance on third parties for continued usefulness of the model.

³⁵ Mount Vernon, "Mount Vernon in 3D: Placing a Historic Building Information Model (HBIM) in Its Landscape," news release, 2015, Digitizing Mount Vernon, <http://www.mountvernon.org/research-collections/preservation/digitizing-mount-vernon/>.

2.4 Conclusion

The NPS and its practices and guidelines are important to historic resource documentation and management. They set the standard treatment and practices for the nation's historic resources which preservation adheres to. The methods of documentation utilized by NPS mentioned in the previous text are just a few of many options available to the preservation community. The evolution of the technology-assisted field recording and measured drawing creation has increased speed and accuracy of measured drawing documentation. With the implementation of the maintenance and management tracking advancements, the nation's historic resources can be better preserved for future generations.

BIM has already proven itself as a valuable asset to the new construction and resource industry. With attempts to apply BIM for historic resources, the preservation community can gain an valuable tool for the documentation and management of resources. Innovation must move forward so prototype applications can be tested to help create an applicable tool that brings BIM to the preservation community. Through the literature review presented in this chapter and previous background knowledge of BIM for new construction, a methodology for HBIM was created for this thesis and is presented next.

CHAPTER THREE

METHODOLOGY

3.1 Research

The following section describes the first step of methodology. A questionnaire determined current best-practices for documentation and management. The questionnaire findings illuminated that house museums are an ideal BIM application candidate.

To understand if Building Information Modeling (BIM) is applicable to the preservation field for documentation storage and management, it is necessary first to determine what software is currently in use by preservation experts. Within the field of preservation, experts in multiple fields work together to maintain cultural resources. For this reason experts in engineering, architectural, construction and restoration, and heating ventilation and air-conditioning design and modification were asked to complete a short, seven question survey designed to identify and understand current practices. The questionnaire is attached as *Appendix A*.

The questionnaire opens with a question about the percentage of preservation projects performed by a firm. This provides a base line to insure that the interviewee is actually involved in projects within the preservation field. The survey next moves to provide questions to discover if computer-aided drafting (CAD) software is instrumental to the company's process and, if so, which programs are in use. This line of questioning aids to determine what software technologies are currently employed in projects by industry professionals within preservation.

This thesis seeks not only to determine the correct use of CAD but also the applicability of BIM for documentation and management. It is important to understand a company's accessibility, use, and storage mechanisms for the resulting document produced from CAD and other software. The questionnaire provides room for the explanation of the reasoning behind each company's methods. Moving the discussion from CAD to BIM, the survey asks if any prototype projects employing BIM have been performed by the company. Based on information found during the literature review, this survey assumes that no company uses BIM exclusively. BIM is experimental within the preservation field at present. The question about employing BIM on pilot projects is open ended to allow for correction if a firm does employ BIM on all or most projects, though this was not encountered in any of the surveys.

Finally, the survey's closing question is specific to the preservation professionals for which this thesis focuses, cultural resource owners and managers. The survey provides space to include information on what methods cultural resource owners utilize for documentation and management, such as memory-based knowledge, excel documents, paper files, digital files, etc. The survey seeks to determine the direction and current state of recordation in the preservation field. The compellation of the surveys help to direct further research into prevalent preservation software and their application uses to preservation. The survey also opens up conversation for practitioners seeking a better, more comprehensive, documentation and management system for preservation.

3.2 Archival and Management Documentation

The following section describes the second step of methodology. Archival and management documentation on the Nathaniel Russell House was organized into an excel spreadsheet for BIM development. Ten architectural features were selected for detailed modeling in the BIM case study.

Historic Charleston Foundation (HCF) granted access to the archival files and use of the Nathaniel Russell House located in Charleston, South Carolina for the case study for this thesis. The non-profit owns and operates this building as a museum house. Archival hard-copy documents date from the house's finished construction date in 1808 to the present. Working documentation and management hard-copy files recording the house fabric and its restoration and repair range from approximately 1990 to present. The most inclusive digital file is a .pdf copy of the 1996 Historic Structures Report (HSR). This report is eight volumes large, containing nearly 2,000 pages of documentation on the Nathaniel Russell House. Some organizational excel and word format documentation on the Nathaniel Russell House are also housed on HCF's computers. A duplication of at least two different format types of the documentation exists. This is a common policy and procedure for companies to protect and preserve documentation in case of loss or damage.

The files' content ranges from the extensive Historic Structures Report (HSR) completed in December of 1996, to paint analysis performed by Susan L. Buck in 2013. Along with the historical and documented conditions of the house, the files also contain renovation and maintenance schedules and their associated costs. Currently, all

maintenance and repair information is input into an excel document as a summation of work performed in the past three to four years.

This thesis organized the files from HCF in an additional excel file which links with the Revit and Navisworks BIM model. This “input” excel document organizes historical data and management documentation into two categories: historic data and cyclical or ongoing maintenance. The definition of historical data for the purpose of this thesis is any work performed or data discovered that pertains to the original construction or condition of the house. Cyclical or ongoing routine maintenance is separate from historical data. For instance, the maintenance item list includes the repainting of the main house cornice work in the winter of 2015. Both categories have additional columns for detailed information about the task. The “input” excel sheet, generated for this case study includes the following columns for additional information: task or item name, location, date of construction, date of maintenance or repair, cost, contractor, composition, work performed. The excel sheet contains links to scanned pdf copies of additional documentation pertaining to the task. For example contracts or invoices for specific work are retrievable from the excel list.

To test the potential of BIM as a documentation and management system for the Nathaniel Russell House, a critical step of this investigation is building a model. The process of modeling the house allowed for testing of efficiency in documentation of the historic resource, efficiency of the software to depict and organize known details, and for accessibility of the BIM format repository of information by culture resources owners. Due to the scale and time frame of this thesis, HCF personnel aided in the selection of ten

architectural features that had received recent intervention to be modeled in detail in the BIM model. Selecting a prescribed number of features from the organized excel sheet that lists attributes of the entries, enables a more manageable project. Some of the attribute information includes original construction date, maintenance schedule, contractor, and cost details. Another element included in the thought process and rationale behind selecting a few building elements to model in detail pertains to the practical project application. Addressing the needs, requirements, and restrictions is important for understanding the viability of practicing BIM for documentation and management. Historic resource owners may have limited resources to devote to a BIM documentation and maintenance tool, so practicing parceling information for phased implementation is logical.

3.3 Revit Working Model

The following section describes the third step of methodology. The Autodesk Revit procedures used to create the Nathaniel Russell House BIM model are presented to establish a best-practice work flow for historic resource BIM modeling.

BIM is a complex approach and system. BIM implementation, use, and updates require money, time, knowledge, and man power. Stewards of cultural resources may not be able to provide any or all of these requirements. The implementation of the methodology for this thesis intends to address many of these possible constraint combinations. This thesis assumes that the owners looking to employ BIM for the documentation and management of a cultural resource faces all the aforementioned constraints. This is a practical assumption for many stewards of cultural resources today, including the National Park Service (NPS). In 2013, NPS reported a deferred maintenance backlog amount equaling approximately \$11.5 billion due to decades of insufficient federal appropriation levels. Of its estimated 9,600 historic buildings, \$4.5 billion of the backlog is attributed to them.³⁶

First, to address the money constraint, there are options for applying various grants for BIM creation and implementation. Another monetary option includes adding an additional term to already employed term contract architects. Often organizations do not have certain experts on staff at all times but instead elect to contract out certain regularly needed professions. The type of profession in a term contract can include on call plumbers, architects, or general maintenance professionals to name a few. In either

³⁶ Thomas J. Cassidy, Jr. et al., *Historic Leasing in the National Park System: Preserving History Through Effective Partnerships*, report (Washington D.C.: National Trust for Historic Preservation, 2013), pg. 4.

case, there may not be enough money to address the entire resource in complete detail within a BIM model initially. This is why establishing a holistic general model from which to grow and expand as money becomes available maybe an important option. Hiring a consultant to create the model addresses the time, knowledge, and manpower constraints. The steward is presumably already tracking any new instances of documentation and maintenance that occur on the resource for their records. If training an employee to add new information to the BIM management system is not feasible, grants and long-term architectural firm contracts, once again, may come into play for model updates. To make the model feasible and useful, a member of the resource's stewardship team must be able to navigate and utilize the BIM model. The ability to read and access information is not a task that should be contracted out. An effective user interface that provides useful information is imperative. For viewing and model utilization, AutoDesk's program Freedom Navisworks is available at no cost. This software is further addressed later in this chapter.

After collecting existing records of the resource and field measurements as required, the first step in BIM modeling for historic preservation application is to create a digital 3D model. Revit is an Autodesk program software that leads the industry standard in 3D modeling. One of the ways Revit is highly efficient in new building applications is that it employs a "library", or arsenal, of common architectural features called "families." The library houses the families and the families are the manner in which Revit organizes its library. Some of the available families include doors, windows, furniture, electrical, and HVAC components. Revit families are further broken down by types. For example,

the doors family contains bifold-two panel and double-glass variations of the family. These variations of the Library's families are referred to as types. Revit makes families particularly valuable because one can model in flexibility or changeable parameters to new types within the family. For example, the overall width of the door or the size of the glass panes within the door may be editable. This feature of Revit makes it extremely versatile. However, most of Revit's library types are for modern building construction components. Historic types have variable and ornate profiles, shapes, and connections that do not exist in modern construction types. Luckily, Revit provides family templates that allows users to create custom types. Developing and creating custom types to address historical construction elements, while possible, is time consuming and thus costly. Custom family types will be further addressed later in this chapter. In the place of building component(s) or element(s), this thesis utilizes the term "type(s)" in reference to Revit's library terminology throughout this text.

Before beginning a Revit model, it is important to study and understand the structure to be modeled. Looking at plans, visiting the site, and taking additional photographs of elements will be essential during modeling. This includes recording and documenting the chosen historical and maintenance items selected for the case study of the model (if necessary.) Floor plan and elevations drawings of the Nathaniel Russell House were available from HCF, in this specific case. Because HCF does not use any CAD or BIM programs, pdf and hard copies were available through their archive. The digital Autodesk AutoCAD files were made available for this research through Glenn

Keyes Architect and Whole Building Systems - two companies involved in previous restoration and replacement work on the house museum.

Individual floor plans from AutoCAD software were linked into Revit. See *Image 3.1* to see the software screen image of this task. Autodesk programs allow users to link or attach other file formats into the programs. Linked files possess the ability to automatically update and reflect any changes made within the original file visible within the linked file they are associated with. There exists no opportunity to unintentionally edit the linked file within the secondary program, due to a lock feature. Linking files is beneficial at a later stage in the modeling process as well. If changes occur within the original file, that change automatically updates within the linked file. The floor plans within the AutoCAD model space are set to the correct scale to ensure ease when linking the file into Revit. Performing a cleanup of any lines or detailed geometry within the AutoCAD file format also will aid in the development of building the structure in Revit. Additionally, this process also serves as another chance to study and learn the structure.

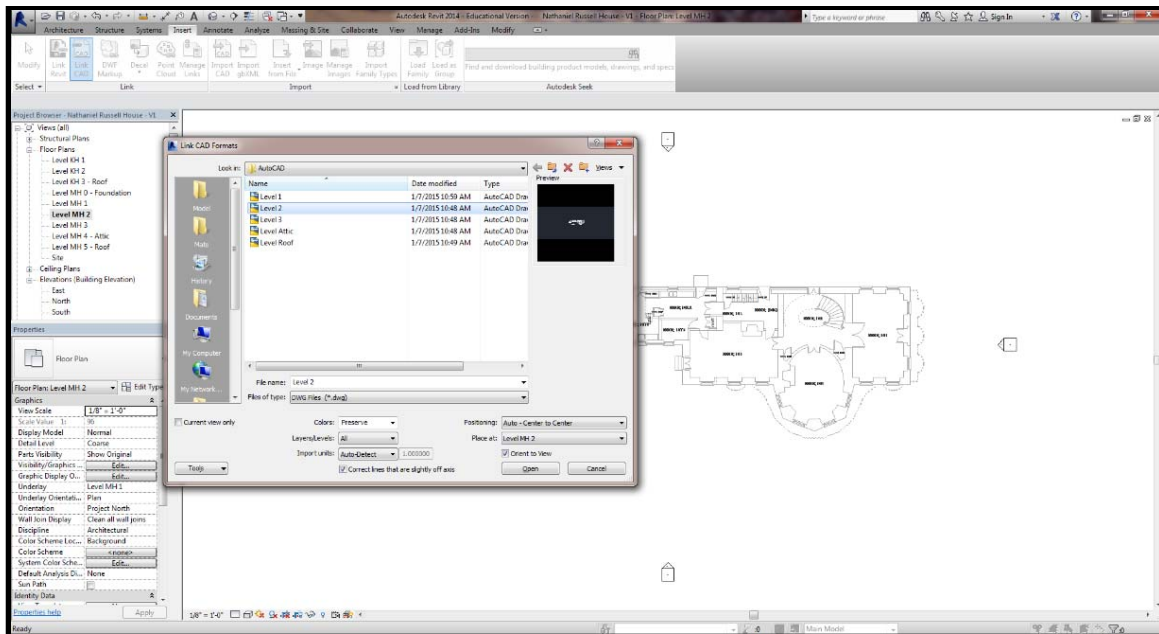


Image 3.1 The image above shows the AutoDesk Revit software screen when linking AutoCAD (.dwg) files to the corresponding Floor Plan Level in the Revit (.rvt).

Revit contains many constraints. These constraints regulate geometry and possible material and level connections within the model. Incorrect modeling or placement of family types produces error warnings and Revit will not model the desired component. A better understanding of the structure's components and construction connections eases the modeling process and prevents error warnings.

For the purpose of this thesis, Historical American Building Survey (HABS) standards for documentation to one-eighth of an inch accuracy is assumed for the provided architectural drawings. Because Revit creates 3D objects, unlike AutoCAD which is 2D drafting, changes made to an object in Revit will update instantaneously to all views that pertain to an element. For example, if a window's trim is edited in plan-view that change is shown simultaneously in elevation without having edited the window in elevation. This makes coordination of drawings among views in Revit automatic.

Before modeling objects in Revit, there are useful tools available for setup that make the process smoother. Setting the building “elevations” or height/levels with respect to the building floor heights organizes the model into levels and creates “views” or floor plans. Later, all types placed in the model are set to variations of these elevations. See *Image 3.2* for an example of the linked AutoCAD (.dwg) files in Revit (.rvt) in 3D view. Next, each AutoCAD floor plan file can link to its correlating floor elevation in Revit. If necessary, the view range in Revit is adjustable so that the CAD drawings are visible. For instance, if there is a one-foot elevation step down into a kitchen or bathroom, the linked CAD floor plan is visible on the level above, at the top of the step, and below, at the bottom of the step, by changing the view range of the floor plan within its property settings. This minimizes modeling work plane clutter and aids to keep the file size lower.

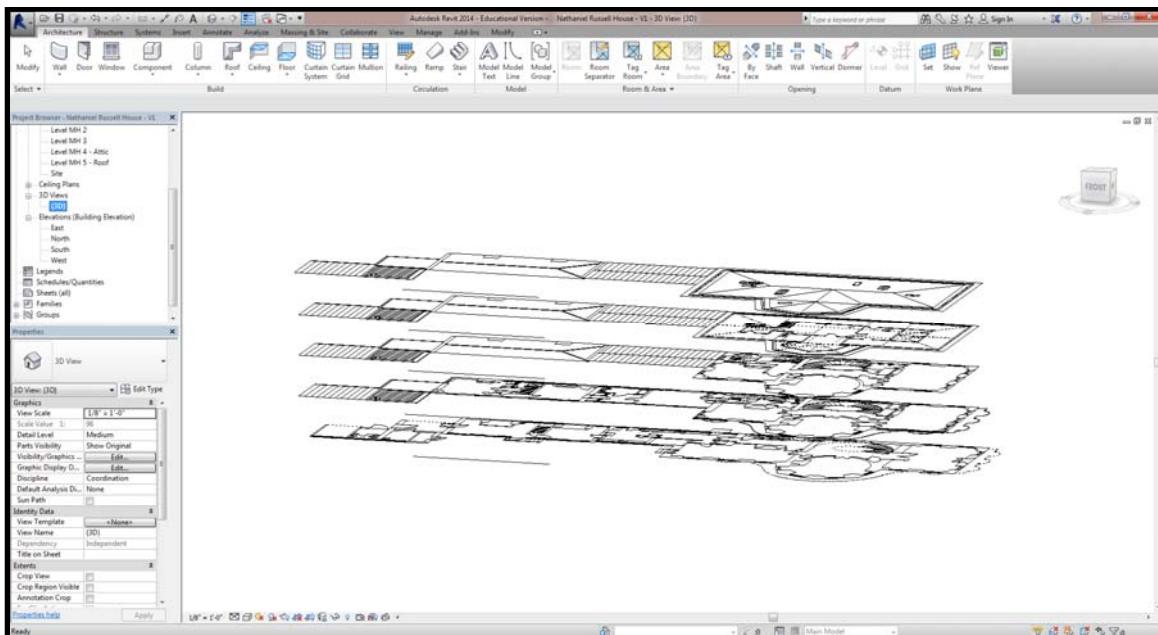


Image 3.2 The image above shows all the attached AutoCAD (.dwg) drawings in 3D view in Revit (.rvt) on their defined elevation layers.

In addition to building the model in segments based on spatial divisions, aka levels, a useful aspect of Revit for historic preservation is the ability to model in chronological segments or phases. Once elevations are established, the creation of different construction phases are implemented. Revit phasing allows the phasing of construction and/or demolition if needed. Determine logical “phases” based on the specific history of the building or resource information found during the excel organization phase. Phases should relate to construction campaigns and maintenance work. In addition to the files organized in the excel sheet, the Nathaniel Russell House HSR provides a detailed narrative with architectural drawings of the seven major phases of the house’s evolution. Revit provides a platform to add and label or delete as many phases needed for a project. For the Nathaniel Russell House model, the initial phases include: Period I – 1808, Period II.I – 1840, Period II.II – 1857, Period IV – 1870, Period V – 1913, Period VI – 1990, and Period VII – 2008.³⁷ See *Image 3.3* for an example of the phase creation dialogue window. When constructing elements or types within Revit, it is important to assign the types to the correct phase. This prevents later editing and confusion. A types’ phasing is always adjustable at a later time in the modeling process if necessary or required.

³⁷ No architectural change occurred between Period III in 1864 and Period IV in 1870, only room use change, resulting in its omission.

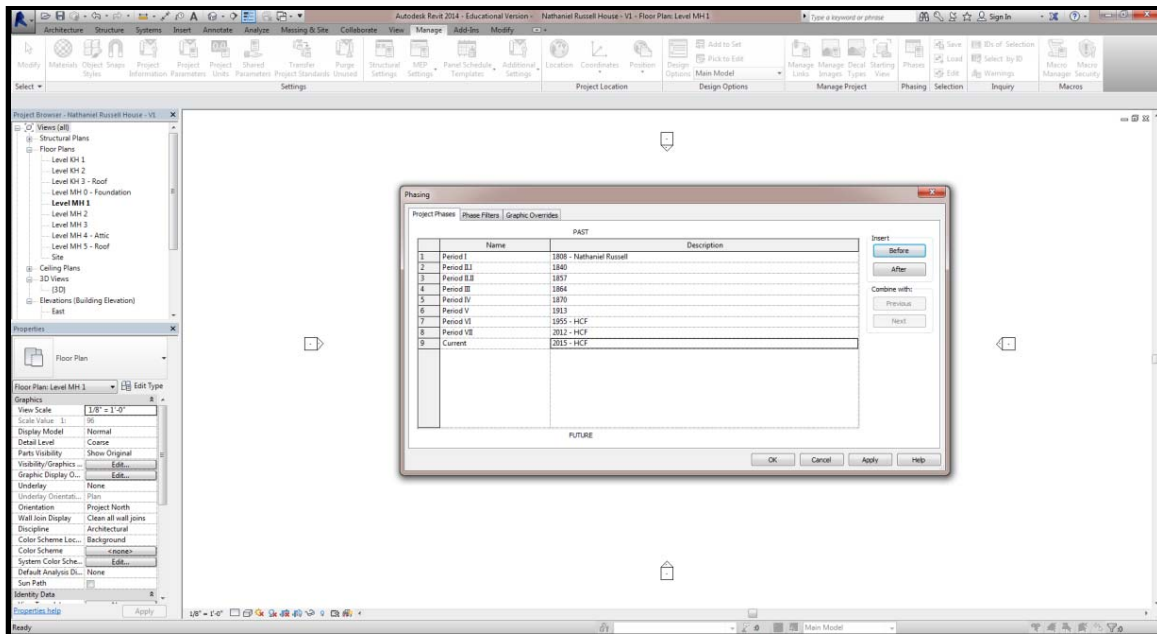


Image 3.3 The image above shows the phase creation dialogue window with the Period I - Current Period for the Nathaniel Russell House BIM model.

Once the phasing setup is complete, wall creation is next. Many historic structures have a variety of wall types. The layers of walls are not always known so generic wall types can be implemented as place holders until known. Creating “types” that depict known thicknesses and any known layering of assemblies saves time and organizational frustration later on in the modeling process. Revit allows complete versatility within the family tree of types.³⁸ Revit allows users to adjust the number of wall layers and the thicknesses of each layer. See *Image 3.4* to see an example of the “edit assembly” dialogue box. There should be one wall type for each assembly encountered in the building. During wall type creation, Revit provides the distinction option between interior and exterior use of the wall. This is another aspect of the program that enhances versatility and information. It can be beneficial to name the walls with this type of

³⁸ The deletion of any unnecessary types is possible within the family tree. This can cut time during modeling by not having to sort through unrequired types.

organizational scheme: Exterior – Brick Structural Masonry – 2’3” Thick or Interior – Wood Stud – 6” Thick. The establishment of an easy and understandable naming system helps with duplication, clutter, and confusion further in the modeling process. Wall type definitions have many more options than those listed here.

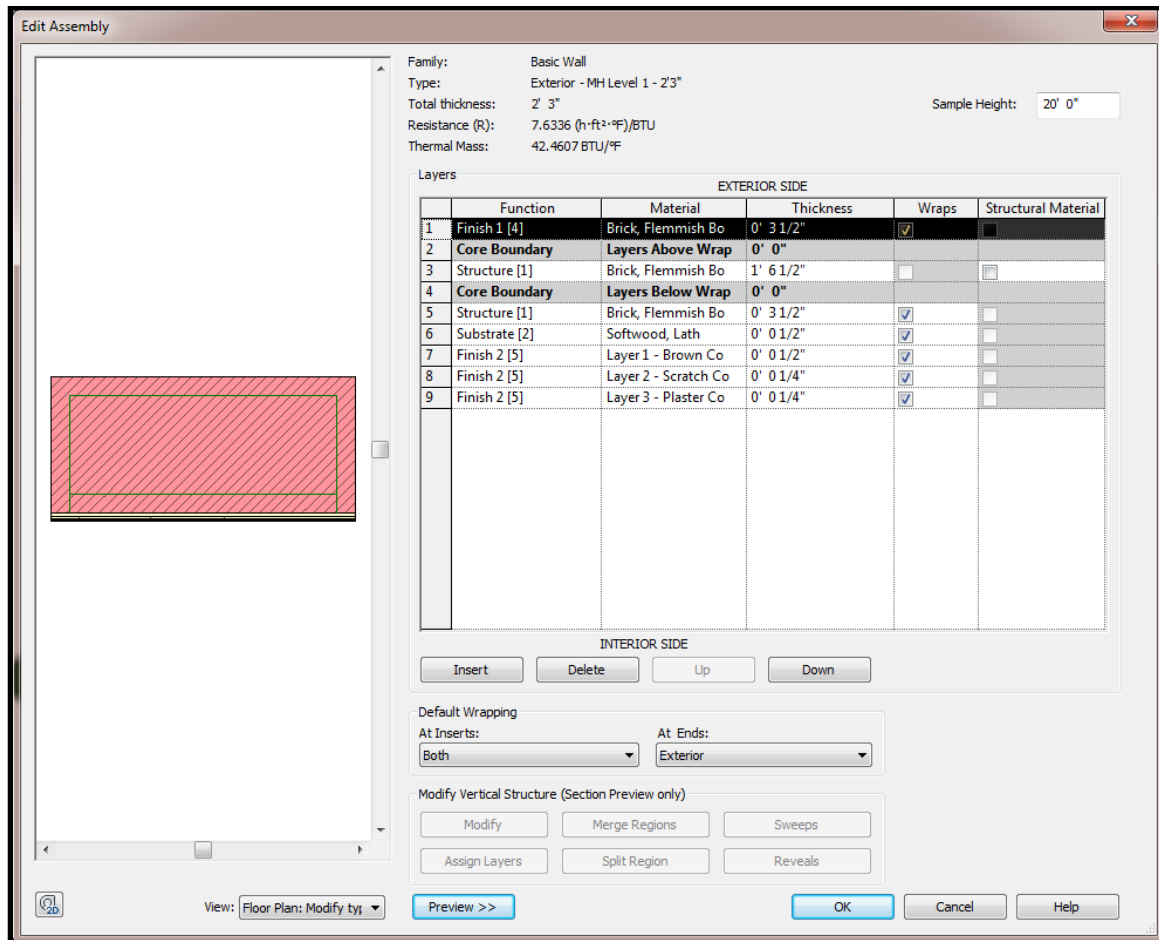


Image 3.4 The image above shows an example of the Nathaniel Russell main house, first floor exterior wall layers in the “edit assembly” dialogue box.

How the wall wraps around inserted elements and at its ends are adjustable within the type properties. Wall wrap refers to the manner in which layers of that wall terminate or cut when other types intersect it within the model. For example, if a wall contains a niche for a statue, the wall layer it cuts through can either wrap into the niche void or the

niche void can cut through each layer, exposing the edges of the layers within the model. Other specifiable parameters in the properties dialogue box are manufacturer information, material condition, a URL link, and cost, to name a few. The ability to change these parameters may have varying benefits on preservation projects. The “type properties” also allows the modification of the elements visual appearance within the model. See *Image 3.5* to see all the property options available. The ability to include this type-specific data introduces the information portion to Building Information Modeling (BIM). This takes the model beyond just 3D representation but adds a 4-dimensional aspect that includes cross-referenced information and a timeline seen through the introduction of phases.

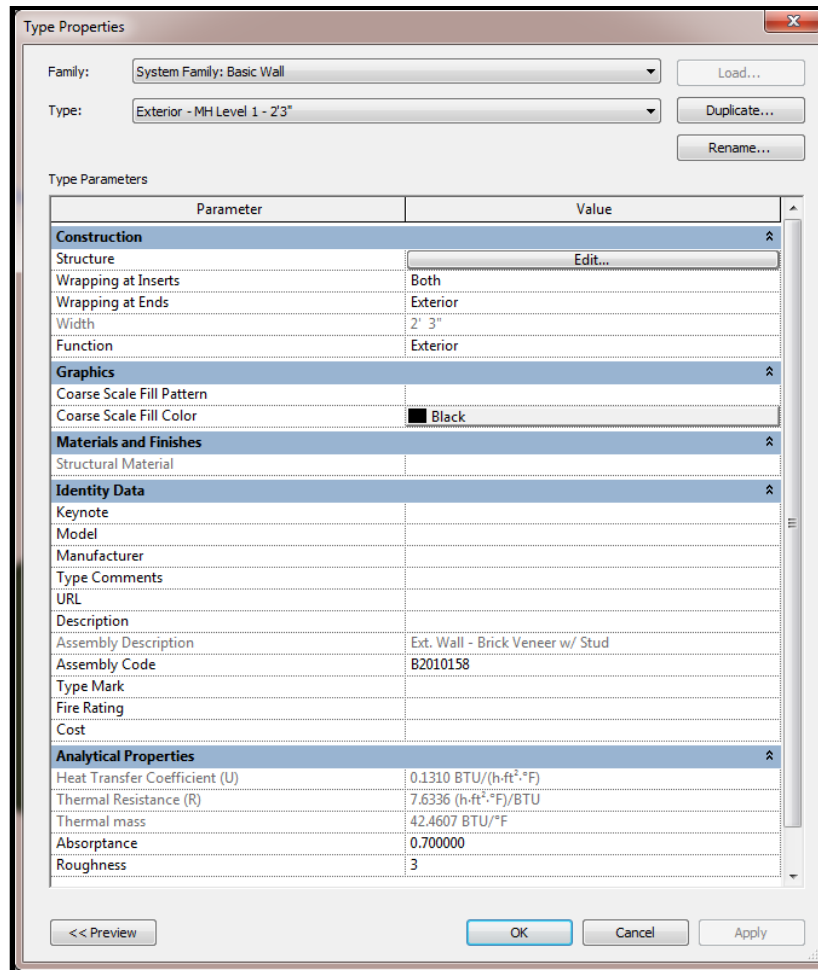


Image 3.5 The image above shows available properties and parameters for the exterior of the Nathaniel Russell first floor main house.

To avoid altering unwanted types already within the model, the “duplicate” command is used and the type renamed for every different type instance required for the structure. The altering of any of the type properties will change every instance of that type within the model to reflect the new changes. The duplication command within Revit is comparable to the standard “save-as” command of other programs. The duplication of a type or the altering of a type’s properties is possible at any stage of the modeling. The fewer major adjustments made to walls in the later stages of the modeling process, the better. While Revit is a versatile program, many later additive types, may change many

aspects of the model undesirably. For example, doors and windows classify as wall based types. Wall based types placed on walls can distort or shift undesirably when properties of that wall change. If a wall changes from one-foot thick to two-feet thick, the window within its frame may shift to the wrong depth within the wall. Parameters of the window type are changeable to correct this instance for the desired placement. Changes are possible, but vigilance during editing is still necessary to ensure nothing shifts out of the intended location. All of this is important due to the highly precise requirement for a historic structure's documentation to be within a one-eighth of an inch accuracy per the Historic American Building Survey requirements. The more multi-faceted the model is, the more beneficial it is to documentation and management of the historic resource.

Once the wall types have been generated, modeling of the types in Revit began. Accurately modeling the walls of the Nathaniel Russell House relied on the AutoCAD drawings as underlay. After, the base and top constraint of each wall was set before placement. These constraints relate back to the elevations defined earlier in the Revit setup. The "phase" of the wall was set during its initial modeling. In the "draw" panel of the modify tab for constructing the walls, different options are available for drawing the walls into the model: line, rectangle, pick lines, start-end-radius-arc, etc. The AutoCAD floor plan is traceable using any of the "draw" techniques. Being highly familiar with the building in the AutoCAD underlay is useful at this stage. Using a scaled underlay saves time when modeling because measurement lengths are traceable or selectable depending on the "draw" technique desired. In the absence of underlay drawings, field measurement can inform the model of exterior and interior walls. Trimming and extending walls,

mirroring elements, and creating arrays are all similar modeling and drafting commands used to build a model.

Floor types within the structure will not vary as much as the wall types. Floor types in historic structures, based on experience, tend to have standard joist depth and wood flooring material consistent throughout the structure. The best practice for modeling is to duplicate the type and implement all known information and constraints to the type before placing it within the model. Again, it is important to understand Revit's constraints. While Revit makes editing model types easier than AutoCAD, small changes can sometimes affect other types unexpectedly within the model. Revit's draw tools for modeling the floors works in the same manner as the draw walls tools. Revit allows the addition of one floor type to the entire level or the selection of individual rooms. This feature is beneficial for different floor covering types or floor board running in different directions that may occur in the structure. In cases with different floor coverings in different rooms, the structural support that makes up the flooring system is the same but the top layer is editable by duplicating the type and changing its properties.

Revit contains ceiling families that are separate from the floors. This is because many modern construction buildings have a large open space for HVAC and electrical equipment between the structural flooring and finished ceiling. Historic structures most likely only contain this feature due to a renovation or an addition to the structure.³⁹ This is another reason why studying the building and planning the modeling steps before beginning are important.

³⁹ The accessible suspended ceiling was patented under the number US 2984946 A on September 8, 1958 by Donald A. Brown.

There are two options for modeling the ceilings of historic buildings in Revit; include the additional ceiling layers, properties, and constraints within the flooring system above or use the ceiling type to model an independent ceiling. To avoid tediously trying to place the ceiling on the underside of the flooring system, Revit provides a “join” tool. Revit will automatically attach the ceiling to the underside of the flooring system. While recognizing the relationship between the two types, the ability to edit each type’s properties individually is still possible. This is another example of Revit’s versatility. Each user’s work flow and intended end use may call for different modeling techniques and sequencing. Because this thesis seeks to have the model act as a user-interface as a documentation and maintenance tool, the “join” option is more useful. Any information on a specific ceiling is editable without negatively crossing data and information onto the flooring system.

The last major structural family to model is the roof. One of the most troublesome elements to construct in Revit is the roof. Settings must be accurate and correct before Revit will allow the type to be “finished” or model it as a solid object. Revit utilizes actual constructability knowledge within its software. If connections or height restrictions are not possible, error messages will appear. The remediation of the error messages must occur before Revit allows the type to “finish” or appear in the model. See *Image 3.6* for an example of model family type creation of the Nathaniel Russell House roof.

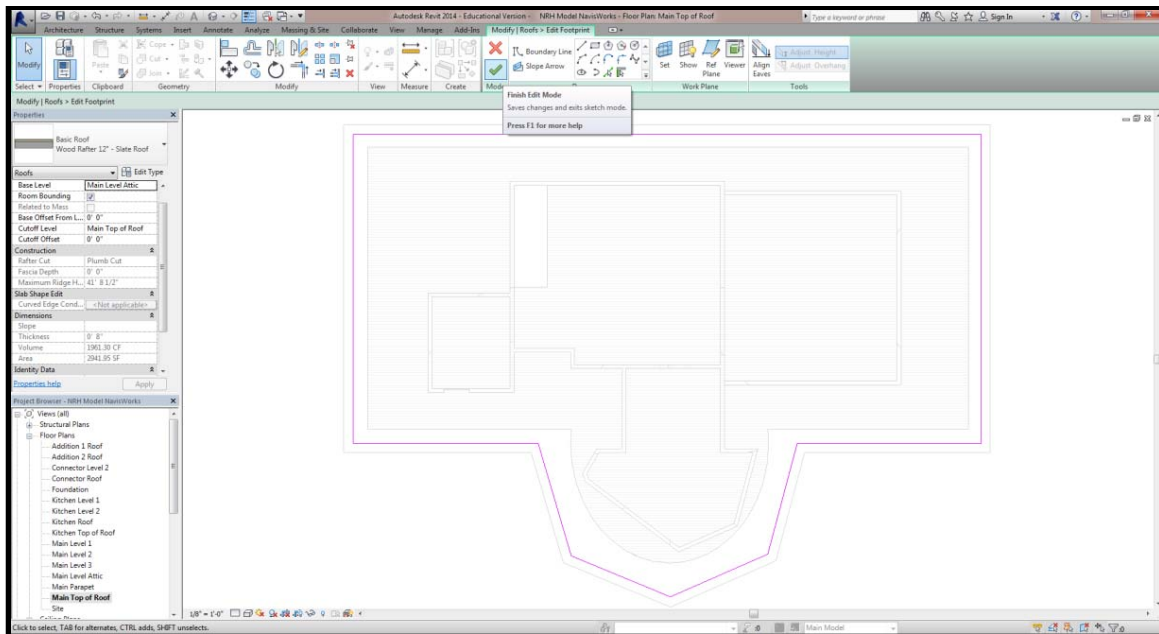


Image 3.6 The image above shows the "Finish Edit Mode" for creating the family type once error codes are addressed.

Revit allows roof modeling through one of the following three possible options: tracing the structure's footprint, a surface extrusion, or by selecting a built surface. Due to the unusual shape of the Nathaniel Russell House, the easiest method to create the roof was by utilizing the "tracing of the structure's footprint" option. By setting a standard pitch to the roof and tracing the building outline, Revit automatically constructs the roof. This means that the placement of any valleys and ridges will appear exactly where the roof slope intersects. The actual construction of the roof details, i.e. valleys and ridges, may not model in their actual place. To insert detailed valleys, ridges, and dormer elements, additional creation tools are available on the Revit Ribbon that houses all the command and creation tabs. Another feature within its tools that increases versatility is the ability to move and edit "design lines" of the roof so that the roof models as it actually appears on the structure.

To allow the Nathaniel Russell House roof to construct accurately, all type properties were set before placing it within the model. This is the same as the creation of wall types before placing them in the model described earlier in the modeling stages. For the model, four different roof types are necessary to model the known phases of the building campaigns. By utilizing the “trace” and “offset” tools in the “roof” command, a flat roof with the correct overhang from the exterior wall face, was finished as a solid object within the model. To get the ridges and valleys of the roof in the correct location, shape editing tools were necessary. The underlay AutoCAD files were instrumental in understanding the roof shape and pitch.

At this stage in the modeling, most, if not all, of the structural elements are in the model. The structural components have the correct phase, layers, materials, and elevations assigned to each one. For the purpose of this thesis, the modeling of the main structural component types are accurate to the knowledge available to date. If the input of the structural components is correct, placing and editing building components in and out of the model is easy. The intention is to create a general model that is editable for later modification as time, money, research, or maintenance events arise as previously mentioned. Once the structural types are all in place, the insertion of generic family type place holders for windows and doors within the model occurs. The designation between interior versus exterior and the known phase each door was set in the properties before placement.

As the Revit model grows and becomes more detailed, placing types becomes more difficult. Revit provides visual tools that help with this issue. The tool temporarily

hides the selection so that the model beyond is editable and viewable. Resetting the visibility of the selection is possible at any time. Revit also provides two additional options to help with this issue. A “section” tool exists within Revit. A section line placed through any point of a plan view creates a new elevation view. The last option is the creation of a new 3D view with the camera tool. This tool creates an image, like a photograph, at any point in the plan view. It allows visible 3D images of the interior spaces.

At this stage in the modeling process, it is now time to develop the specific family types of the features from the excel documentation sheet that were chosen to be modeled. None of the Nathaniel Russell House features were available in the stock Revit Family Library, unsurprisingly. To create new family types Revit provides a large number of templates for family type creation. See *Image 3.7* for the dialogue box containing all the family type templates available in Revit. They incorporate basic parameters applicable to all family types. The door template includes a base wall insertion, exterior versus interior side, the overall width and height, as well as a basic frame detail. This saves time and resources while creating new family types. Other basic templates are available as well. Some of these include a generic wall based model, conceptual massing, and even annotation templates. Revit strives to enable the creation of anything.

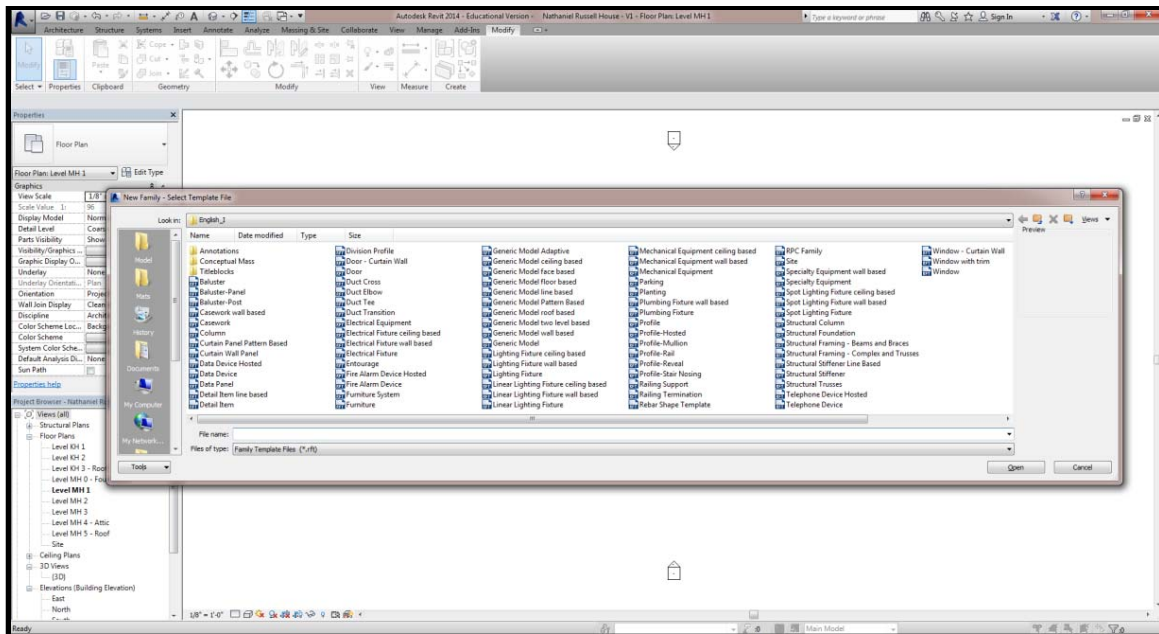


Image 3.7 The image above shows the available templates for Family Type creation.

As mentioned before, historic building elements are, for the most part, not available within the standard Revit library. Creating the many different versions of family types needed for a historic structure is time consuming. The creation of base family type templates is possible. For example, six-over-six window sashes are common in historic structures. It is possible to create a basic six-over-six sash window in the provided Revit window family template and edit it for specific instances, such as a range of widths.

The creation of reference planes define the left, right, center, height, or bottom most placement of the type. To create the profile, sashes, and sills of the window, Revit includes tools that allow the extrusion, blending, revolution, sweeping, sweeping blends, or voids of all the former from drawn basic geometry shapes. It is best to describe this process as a mix between AutoCAD drawing skills and Google SketchUp modeling. Working on the model in four different plans, elevations, and 3D views at once is

common practice during creation. See *Image 3.8* to see an example of the family type creator workspace.

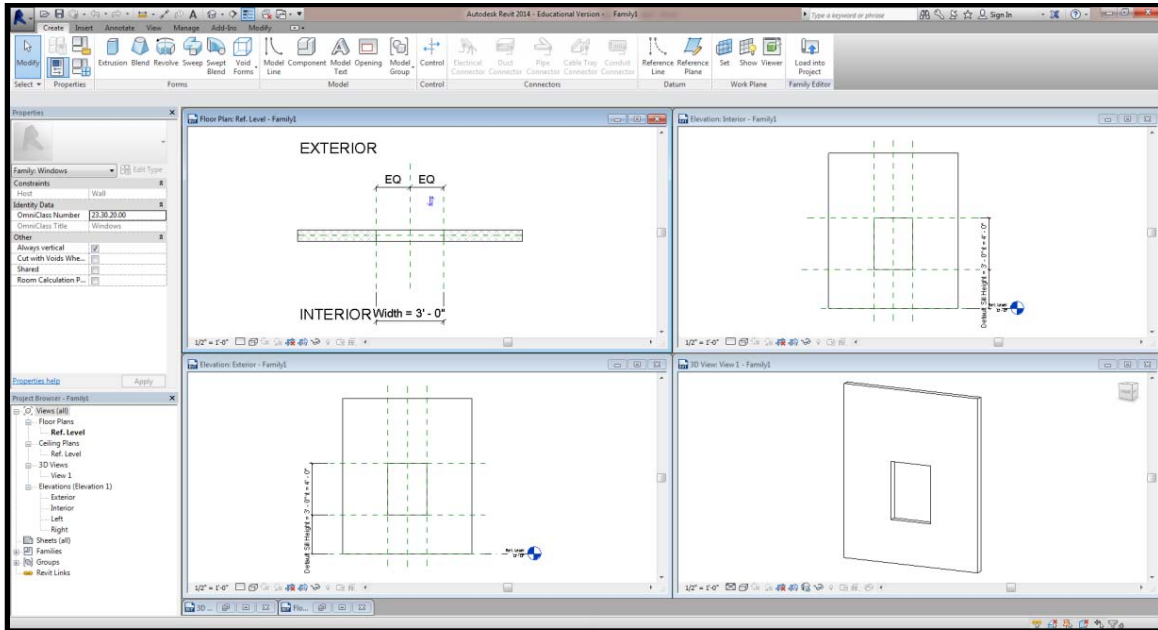


Image 3.8 The above image shows the multi-window work plane for family type creation of a window.

For the creation of a base family type, create stock forms, with basic square profiles, within the family type creation template by using the create form tools as discussed previously. The reference lines set the restraints for the type's shape. Dimension lines added to the reference lines create parameters. The reference lines and parameters define the built geometric shapes and extrusions. These parameters, when done correctly, make it possible to "flex" the family type created. This means, any of the parameters set and defined on the created forms, are editable. A six-foot tall window with three-inch sashes can change to a five-foot tall window with two-inch sashes simply by changing measurements within the type's properties. See *Image 3.9* to see the created parameters for the window family creation in the "family types" dialogue box.

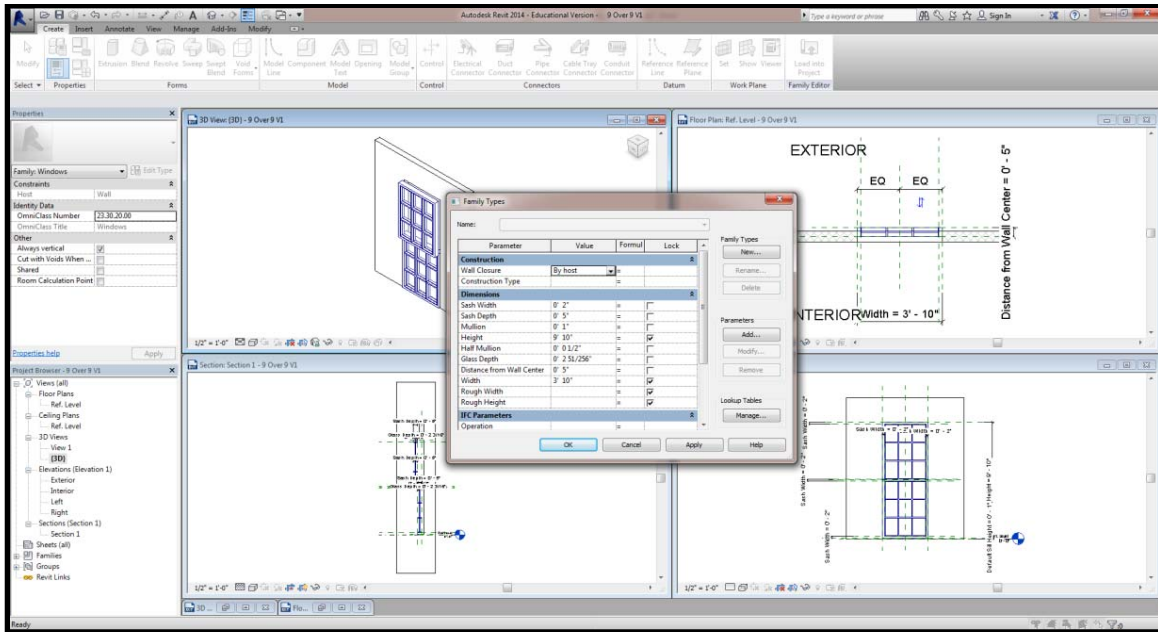


Image 3.9 The image above shows the "Family Types" dialogue box with the created parameters of the newly constructed 9-over-9 wooden sash window for the Nathaniel Russell House.

A newly created project-specific historic library stores the created stock family types. As the need for specific family types arise, the stock types are editable. A developed historic profile library family can replace the stock square profiles on the six-over-six sash window easily. All of the flexible parameters of the window are still available and the type now contains the newly created profile. This way only one element of the type needs to be reconstructed, instead of the entire family type. The save-as function in Revit allows the stock file to remain unedited and available for later manipulation, while creating the new type file. This feature is equivalent to utilizing the save-as function in a Microsoft Word document. The initial building of a historic library is time consuming. However, the establishment of stock library types aid the production

process later by saving time and money and is an opportunity for collaboration as HBIM gains momentum.⁴⁰

After the creation of the stock file, the addition of the appropriate Nathaniel Russell House detailing or profiles occurred. The newly created historic family type loads into the active building model. Flexible parameters change to reflect the type in the structure as does the phasing and data entry in the type properties. Historic family type libraries lead to an easier use and implementation of creating BIM models for historic resources.

A holistic BIM model is now available for the historic resource. See *Image 3.10* for a photograph of the completed Revit BIM model. The information such as the manufacturer, phasing, and cost attached to the property types makes this model a BIM model and not just a 3D model. The model becomes a repository of manufacture, maintenance, and other management data. The Revit file links into AutoDesk Navisworks, in a similar manner that the AutoCAD linked into Revit, as a means to expand the information of the model and to include even more dimensions and usability. The benefit of using all AutoDesk programs is they easily link into one another. Also, a variety of the navigational and editable tools are similar or the same.

⁴⁰ It would benefit the preservation field to establish a Revit library repository of historic types. The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) has already established and continues to add to a Revit library specific to its field of expertise. The templates for designing family types and already built library types is available for purchase. The purpose of the library is to “provide large-firm capabilities to smaller-firms.” If a similar repository of historic elements was established, this would aid in the cost and time required of historic resource owner’s to implement models for documentation and management purposes.

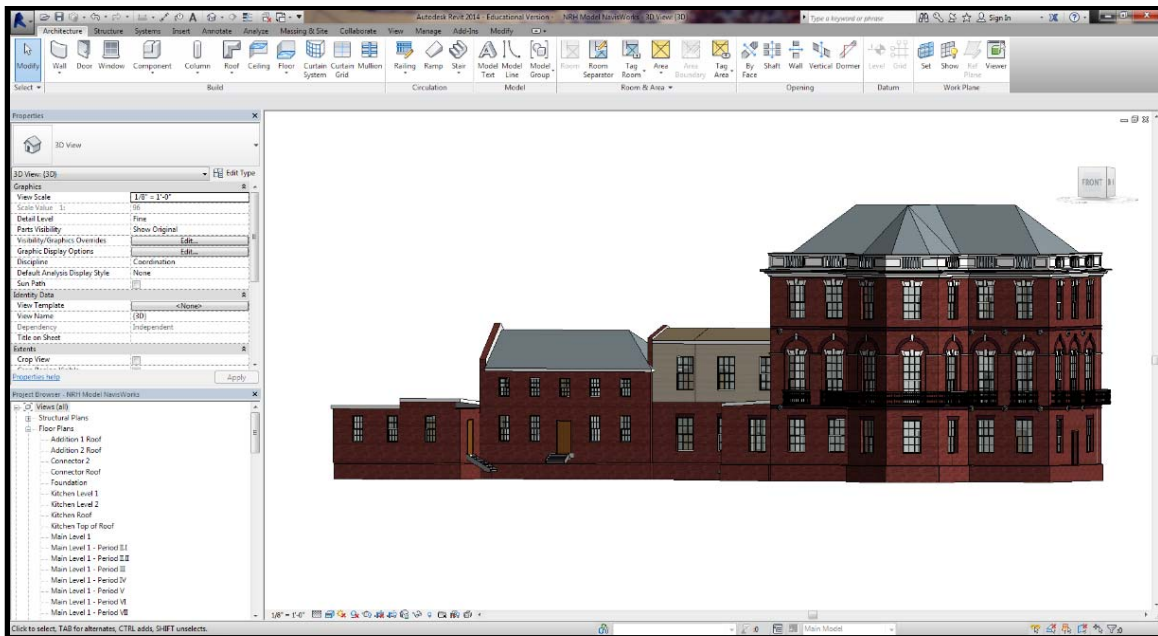


Image 3.10 The image above shows the completed "working" Revit model of the Nathaniel Russell House.

3.4 Accessing Documentation through Navisworks

The following section describes the fourth step of methodology. The section outlines the procedures for integrating the Revit model into Navisworks. Methods for archival and management documentation linkage within Navisworks is detailed. A description and analysis of the end users testing the model's accessibility and success completes the methodology.

Revit software enables modeling a structure and landscape. Certain object properties such as cost, manufacturer, and description are editable in Revit. To add additional layers of accessible documentary and management resources, the model links to Navisworks Manage. Navisworks software enables stakeholders to holistically integrate, analyze, and communicate project data in an integrated model. Navisworks enables three different file types depending on the work dynamic needed for the model. These file types are Navisworks Cache (NWC), Navisworks “Working File” (NWF), and Navisworks “Delivered” (NWD.) The NWC file uses the source file, specifically a Revit file, to load into Navisworks. If the NWC file is newer than the source Revit file, the model generates quickly. If the Revit file is newer, the NWC regenerates to show updates performed in the source Revit file. This means that changes made in the source file automatically propagated forward into the Navisworks without having to resave a new Navisworks file. The NWF file type is for on-going projects that will have changes in the source files that creates the NWC files. Simply put, the Cache file types combine, or append, in this file to enable the updates from the source file of progression and changes occurring during a projects lifespan. Lastly, the file is savable as an NWD file

when the project is complete or a snapshot of the project needs sending out for others to utilize and view. This file type contains all design and geometric information from appended Cache files. Updates and changes in source files do not regenerate in Navisworks with this file type.

To create a usable model in Navisworks including the phasing defined in Revit, the phasing filters must be set in Revit. Phase filters set to “show demo + new” and the phase set to “Phase I -1808-1832” shows the house at its beginning. To create the needed Navisworks file, the Revit model under the previously mentioned phasing filters exports as a NWC file to the desired folder location and can be named under its phasing period. The exportation of each construction and architectural period, Period I-VII in the case of the Nathaniel Russell House, defined in Revit, exports and saves in the process mentioned previously.

All of the exported NWC files “append” into one Navisworks file. Without creating a cache file of each phase’s types, new and demoed, only the currently set phase in Revit would appear in the Navisworks file. Navisworks recognizes if there is a duplication of elements in merged cache files, the program does not recreate them so there is no concern of redundant architectural elements. So that Navisworks can recognize a duplication of elements, only “append” in the first file and “merge” in the remaining files. See *Image 3.11* to see an image of the Navisworks work plane to “merge” cache files. To define the phasing of the model created in Revit, utilization of the “timeliner” feature in Navisworks is necessary. Otherwise, none of the new and demo elements phase in and out, instead they all exist at once.

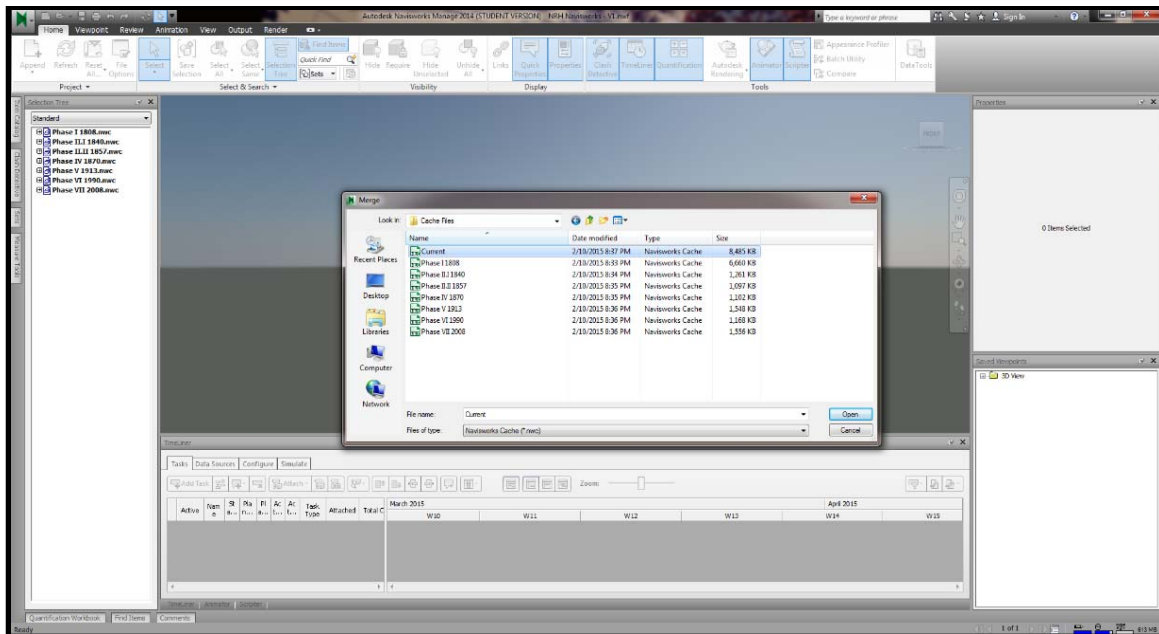


Image 3.11 The image above shows the Navisworks software screen when cache (.nwc) files are "merged" into the program.

Navisworks takes all the geometric and type information created in Revit and organizes it in a “selection tree.” Its appearance is similar to that of standard computer file organization with collapsible or expandable files. See *Image 3.11* to see the “selection tree” in Navisworks. Each cache file appended in will appear as named. As the file name expands created levels or elevation names are visible. Upon further expansion of the levels, a list of all the family types on that level appear. The “selection tree” continues to break the model down in this manner until the base type brakes down to its smallest layer. This allows users access to every individual layer of an element placed in the model. For example, in *Image 3.12* the wall type category under “level 1” expands to show every wall type and each wall type expands to show each layer defined in that wall types properties. To create the “timeliner” of the phasing more time efficiently, the “find items” feature helps.

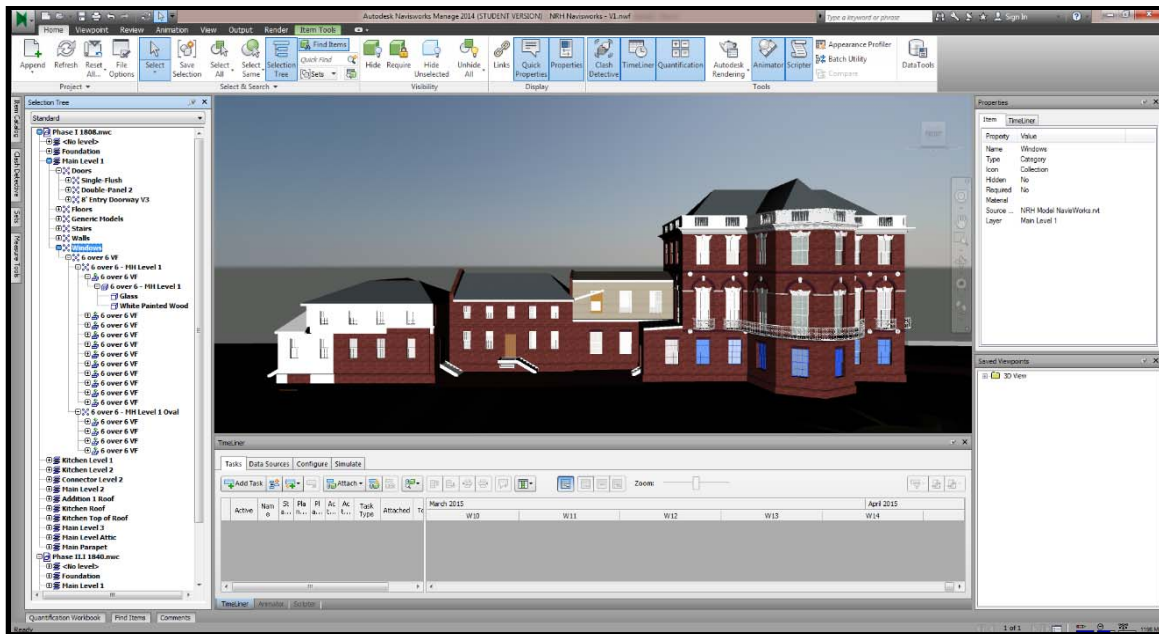


Image 3.12 The image above shows the "selection tree" dialogue box with the organized model types.

The “find items” feature enables users to search for any item(s) in the selection tree through a multitude of search criteria options. The search criteria has selectable category types, properties, conditions, and values. See *Image 3.13* for an example of the search set dialogue view in the Navisworks software. To quickly access each element under its phase filters appended in the cache files, the following search categories are most useful: category as element, property as phase created or phase demolished, condition as equal (=), and value as the desired phase. A separate search for each phase created and phase demolished, the property category, every phase period, and value, is necessary. After the definition of all the search categories, the “find all” option locates all instances that meet the criteria in the model. The selected instances are savable as a “set” in Navisworks. “Sets” does not permanently group the instances together, but creates a short cut to select all the instances without having to use the “find items” tool again.

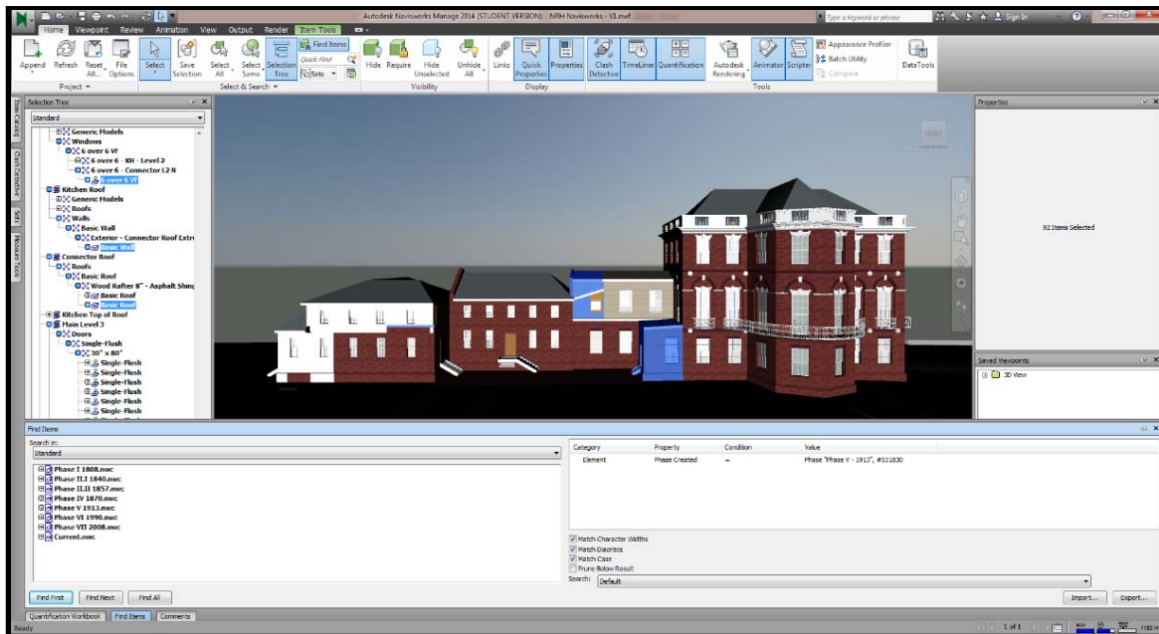


Image 3.13 The image above shows the "find items" dialogue box to create "sets" to be put into the "timeliner" application.

Once the establishment of a “set” for every element created during each period and every element demolished during each period is complete, the next step was implementing the timeliner tool. The timeliner tool creates a timeline simulation of the model elements defined by a schedule. The establishment of a schedule is necessary to begin. Navisworks can automatically generate schedule task names based on element names in the project, by linking a schedule created in an excel file or other scheduling program, or by manual line-by-line input through the “add task” option. A task for each saved set, done previously, is included chronologically in the timeliner window. Each task line provides information input to define the task name, schedule dates, costs, behavior, and set attachment to name a few. The inclusion of this information provides data and scheduling for the timeline simulation to work affectively. After the inclusion of all tasks, the simulation is available. A task is developed then linked to a schedule in the

timeliner. This creates a sliding bar that enables the model to display at any phase. If the slide bar is all the way to the left the model appears in Period I and if it is all the way to the right, the model is in its current state; all other periods exist in between. This simulation is savable as an independent video file. This feature is potentially beneficial as an educational tool to the public as well as many other applications. Navisworks also provides an animator tool that creates fly-through videos within the model that could be an additional benefit for public education. This additional feature however, is not a priority task within the perimeters of this thesis but is worth mentioning as an additional avenue to explore for historic resource owners.

The attachment of data and documents to the individual elements within the Navisworks model was the next critical step in developing a prototype BIM management tool for HCF to use at the Nathaniel Russell House. Navisworks allows additional information non-native to the BIM software to be attached to individual elements through the use of external links. This includes URL addresses and document types such as pdfs, jpegs, or excel. An additional method for adding information is available in the element's properties dialogue box generated in Navisworks from Revit element property information. The properties dialogue box contains standard tabs with the element information retained through input from the Revit modeling stage. Other tabs also exist that contain the element id number assigned to every Revit element and color and material value. Some of the information provided in the standard tabs is not useful for the purpose of documentation and management but is instead software specific element data. The creation of a new tab allows input of any desired information. To serve a purpose for

documentation and management, the intention of this additional tab is to provide quick access to basic information that may be needed while utilizing the model. The line items included are the same as the Excel document developed at the initial start of data collection. The line items are as follows: task or item name, location, date of construction, date of maintenance or repair, cost, contractor, composition, work performed. The versatility of the line item additions in the documentation and management tab is flexible depending on the users wants and needs for quick data retrieval.

Once the BIM model is complete in Navisworks, it needs to be available to the resource owners who may not be able to afford the Autodesk Licensing costs of Navisworks. It is critical that the file is usable and for the model to have an effective user-interface to garner information and data. Otherwise the money, time, knowledge, and manpower that went into the initial model will be useless. Luckily, Autodesk provides a free download of Navisworks Freedom. Opening the BIM model to access the data is then available for free through this program. In this case, the owner will only access and track data already in the model but will not be able to input the new data themselves. They will instead compile the data for input at a later date, ideally on a scheduled maintenance increment, by whomever is the model builder or creator of the BIM model. The intended benefit of a well built and managed BIM file is that the historical and maintenance data is available in one all-encompassing user interface that is accessible on command. The need to comb through old file cabinets or vast digital folders and files searching for information could be obsolete. There would be great advantage to

curating historical data and performed maintenance in an accessible format and easily retained through changing times and personnel.

To learn if a BIM model of a resource is beneficial to the historic resource stewards, it is important to test the application. Testing subjects included a variety of participants with and without prior exposure to BIM models. Navisworks Freedom 3D viewer, suggested previously, is the platform display program for the user-interface. During the semi-structured “test”, participants have time to explore and learn how to navigate around the BIM model. The introduction of three different possible real life scenarios provide the participant a chance to navigate and find the data pertaining to the given task. Participants have the opportunity to discuss and explain any issues or successes they experienced during the scenarios. The user feedback is open-ended to allow for unstructured dialogue between BIM creator and user. Understanding user success or failures of the data retrieval is important as are general visual impressions and expectations. A copy of the scenarios and open ended questions presented to the participants is available in *Appendix B*.

CHAPTER FOUR

CASE STUDY: THE NATHANIEL RUSSELL HOUSE

4.1 Introduction

Chapter 4 presents a case study to explore the untapped potential for the documentation and management of a historic resource afforded by Building Information Modeling (BIM). The retention, tracking, and useful access to knowledge garnered by architectural analysis and the documentation associated with management activities of a historic resource are difficult to maintain. It is important to the stewardship of historic resources, however, to ensure that these treasures last for future generations. Knowledge and information is lost through an assortment of human error, technological failures, or natural causes. As a potential solution to this inherited problem of lost information, this case study explores the utilization of BIM.

The Nathaniel Russell House, shown in *Image 4.1*, is an ideal candidate for a case study. Throughout its 200 plus year history, the house experienced a multitude of owners and changes. The house exhibits an architectural and cultural importance which substantiated the house's acknowledgement as a National Historic Landmark (NHL) in 1974. Today, the stewards of this historic resource, the Historic Charleston Foundation (HCF), interpret the history of this house to the public as a museum. To best serve the public and the historic fabric of the house, HCF works to retain all the discoveries and maintenance documentation of the structure. These energies lead to a longer lasting and a more beneficial cultural resource. BIM is a potential resource to help HCF and other historic resource owners with this type of records management. The constraints put on

owners of historic resources, with respect to records management, include monetary, time, knowledge, and man power availability. Keeping these constrictions in mind, the research has two phases. First, the primary researcher developed a working BIM model of the Nathaniel Russell House as was discussed in Chapter 3. After this, individuals with limited BIM experience tested the “working” BIM model of the historic resource. The case study is designed to explore how feasible it is to model historic resources and attach their accompanying management documentation and to better understand if non BIM trained preservationists find this technology accessible and useful.



Image 4.1 The above image shows the Nathaniel Russell House in 1940. Image courtesy of the Library of Congress. 51 Meeting Street, Southeast Elevation of the Nathaniel Russell House. Photograph, September 1940 by C.O. Greene. (Library of Congress, Prints and Photographs Division HABS SC, 10-CHAR,2—1).

The study predicts that significant difficulties will be encountered in modeling a historic resource. Familiarity with the software predicts limitations within the BIM program's ability to attach and/or link pdf and jpeg file types, such as management records, within the program. Encountering these types of difficulties does not suggest that BIM is a dead end for preservation applications. Even if specific problems are a hindrance at the time of the study, recognizing the potential behind BIM's versatility is important. Ongoing work to refine the software and develop best practices for documentation and management in BIM can precipitate an increasingly good fit for historic resource management and BIM technology.

4.2 History

The Nathaniel Russell House lot is Lot 247, denoted in the original Charleston, South Carolina Grand Modell of 1680, outlined in red in *Image 4.2*.⁴¹ The lot was first owned by the Percival family, from 1694 through 1723. These first owners resided in England during their ownership.⁴² Lot 247 sold to William Dunning, also an English native, in 1723. While no deed was located for Lot 247, the lot most likely sold in 1732 along with other property owned by Dunning, including Lot 241 located on the same street.⁴³

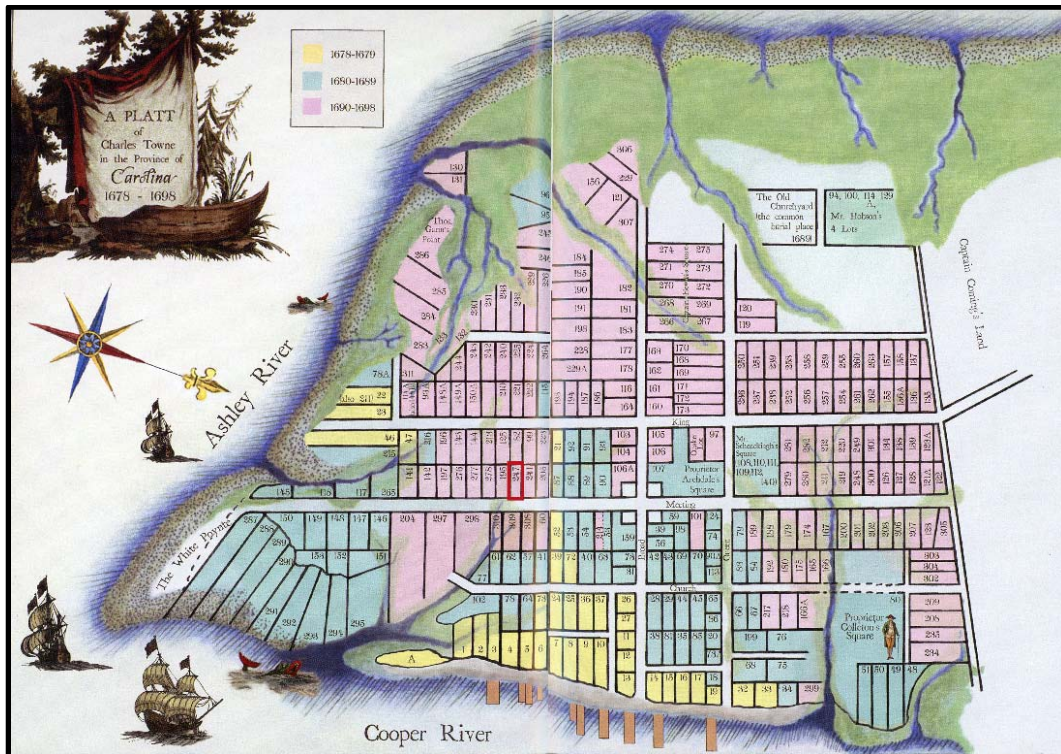


Image 4.2 The above photograph shows the Charleston Grande Modell. Lot 247, outlined in red, denotes the lot where the Nathaniel Russell House sits. Bates-Leland, 1698 Map. Charles Towne as laid out in the certificates of admeasurement and Surveyor's Notebook for the period to 1698. By S. V. Bates and H. C. Leland, graphics and artwork by D.W. Tessinger, 2007.

41 Orlando Ridout, V and Willie Graham, *An Architectural and Historical Analysis of the Nathaniel Russell House*, report, vol. I (Charleston, SC: Historic Charleston Foundation, 1996), pg. 2.

42 Ibid.

43 Ibid.

John Fraser owned the lot around 1732. Fraser was the first owner known to improve and build upon the lot.⁴⁴ Archaeology work performed by the Historic Charleston Foundation (HCF) in 2012 located some of the foundations belonging to the Fraser-era original structures.⁴⁵ The property passed into Alexander Fraser's hands, the son of John Fraser, after his mother's death in 1772.⁴⁶ A. Fraser sold the property to William Greenwood and Nathaniel Russell, in 1779.⁴⁷

Nathaniel Russell, born in Rhode Island in 1738, did not purchase property in Charleston until 1779. He purchased a total of three different properties during this year. Nathaniel Russell already had a well-documented life in Charleston society before these purchases. The purchasing pattern suggests that Nathaniel Russell's wealth did not reach a level that enabled him to expand his assets and mark his social standing until this point.⁴⁸ Leading up to these purchases, Russell pursued a mercantile business. His trade occurred between Charleston, Newport in New England, continental Europe and West Africa to name a few other locales. He improved his financial status significantly throughout the 1770s leading up to his Charleston property purchases.⁴⁹ One of the (3) 1779 purchases was a house at No. 16 East Bay. Nathaniel Russell lived in this house for

⁴⁴ Orlando Ridout, V and Willie Graham, *An Architectural and Historical Analysis of the Nathaniel Russell House*, pg. 3.

⁴⁵ Ibid.

⁴⁶ Ibid., 4.

⁴⁷ Ibid., 5.

⁴⁸ Ibid.

⁴⁹ Ibid., 8.

approximately 20 years.⁵⁰ From 1781 to 1783, Russell left Charleston for England after the seizure of Charleston by British forces in 1780.⁵¹

Upon his return to Charleston, Russell began to reestablish himself in local society and business. Russell acquired more real estate and bought out William Greenwood from his shares of Lot 247 on Meeting Street sometime between 1784 and 1785. At the age of fifty, in 1788, Russell married Sarah Hopton. Sarah, 36-years-old, was the daughter of a prominent family in the Lowcountry. She held substantial wealth of her own through a legal right to real estate inherited from her father's estate.⁵² The Russells had two daughters; Alicia born in 1790 and Sarah born in 1792.⁵³ No known records exist that state the exact time the Russells decided to build a home on Lot 247 but records indicate that their decision was made sometime between 1806 and 1807. To further demonstrate Sarah's own prosperity independent of Russell, research indicates that the bricks used to build the house may have been acquired from the brick plantation retained by Sarah's father's estate along the Cooper River.⁵⁴

The house was completed on May 10, 1808 as shown in the rendering in *Image 4.3*. An advertisement, documents the original painter of the house as Samuel O'Hara. In an ad he states that no other building in Charleston equals the work he performed on Nathaniel Russell's house on Meeting Street. Some of the earliest known repair work and changes occurred to the house not long after the structure's completion. A *Charleston*

⁵⁰ Orlando Ridout, V and Willie Graham, *An Architectural and Historical Analysis of the Nathaniel Russell House*, pg. 9.

⁵¹ Ibid., 10.

⁵² Ibid.

⁵³ Ibid., 11.

⁵⁴ Ibid., 10-11.

Courier article from September 11, 1811, for example speaks of a violent tornado that unroofed the house.⁵⁵

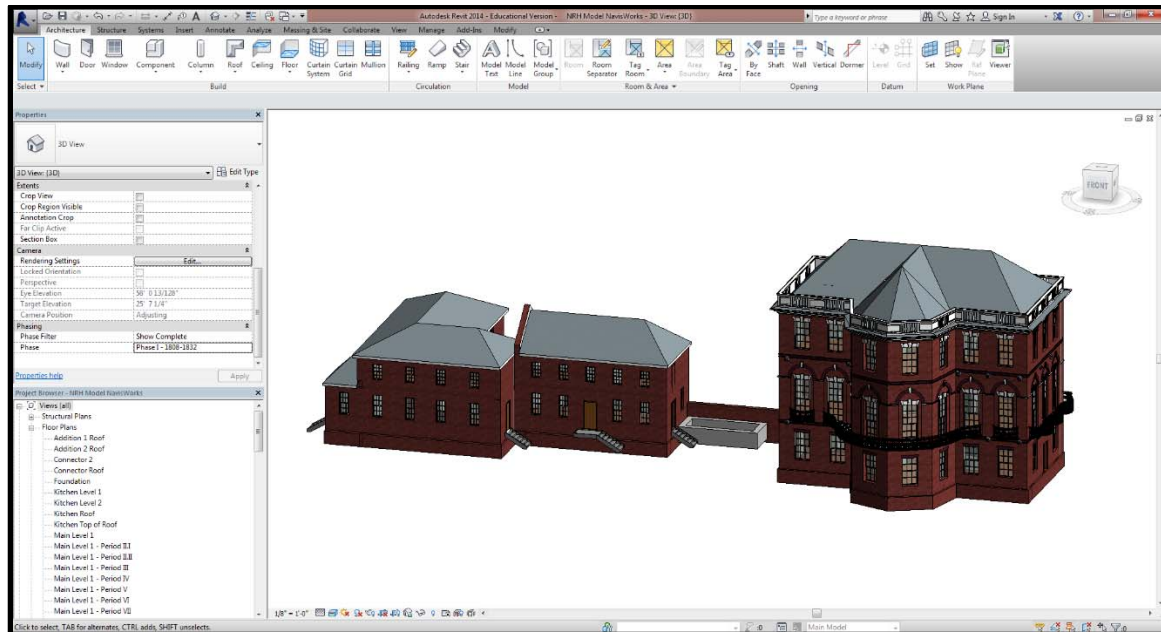


Image 4.3 The above image shows the Revit rendering of the Nathaniel Russell House in Period I, c. 1808. Model made possible by Glenn Keyes Architects and Ridout, Orlando, V, and Willie Graham. *An Architectural and Historical Analysis of the Nathaniel Russell House. Report. Vol. I. Charleston, SC: Historic Charleston Foundation, 1996.*

Alicia Russell married Arthur Middleton shortly after the completion of the house at 51 Meeting Street and moved in with her parents. Written documentation by attendees speak of the many parties and events held at the house by the family during Nathaniel Russell's lifetime. The first grandchild, Nathaniel Russell Middleton, was born in the large front bed chamber on the third level in 1810.⁵⁶ See *Image 4.4* to see the room as it appears today. The family continued to live in the house after Nathaniel Russell's death on April 11, 1820.⁵⁷

⁵⁵ Orlando Ridout, V and Willie Graham, *An Architectural and Historical Analysis of the Nathaniel Russell House*, pg. 15.

⁵⁶ *Ibid.*

⁵⁷ *Ibid.*, 25.



Image 4.4 The above image shows the east third floor bed chamber as it appears today. This room has not been restored but is utilized for school group learning activities. Nathaniel Russell House. Historic Charleston Foundation. Photograph by Laura Lee Worrell.

After Nathaniel Russell's death, the property passed to Sarah Hopton Russell, Russell's wife. She was the owner briefly, until her death two years later in 1832.⁵⁸ Nathaniel and Sarah's younger daughter, Sarah Russell Dehon, who was widowed just four years after she married in 1817, inherited the house after her mother's death. Sarah's oldest child, Sarah Russell Dehon, married Reverend Paul Trapier in 1833. The marriage took place in the home at 51 Meeting Street. The Trapier's had twelve children between 1834 and 1856.⁵⁹ During this period some of the children moved into the house with their spouses and growing families. The Russell House experienced room use change due to an

⁵⁸ Orlando Ridout, V and Willie Graham, *An Architectural and Historical Analysis of the Nathaniel Russell House*, pg. 26.

⁵⁹ *Ibid.*, 29.

ever growing number of occupants. Sarah Russell Dehon died in 1857 and the property sold that year.⁶⁰

Governor Robert F. W. Allston purchased the house after Sarah Russell Dehon's death. The Governor, his family, and slaves lived in the house until the 1861 bombardment of Charleston that began the Civil War. The house survived the 500-day take-over of Charleston by Federal Troops and the family moved back in. A year after the family returned in 1863, Governor Allston died. His wife opened the house as a female academy in order to remain fiscally secure. In 1870, the house is sold to the Sisters of Charity of Our Lady of Mercy who ran it as a convent and girls school.⁶¹

In 1908, the house became a private residence again. It was purchased by the Lane Mullally family.⁶² The house sold again in 1913 to Mrs. Francis J. Pelzer. The house and grounds underwent many additions and changes during her ownership. After her death 1952, the house was on the market again. For three years the house sat unsold. In February of 1955, HCF sought donors to support the purchase of the house. Through a \$32,500.00 anonymous donation and a Charleston newspaper fund-drive campaign raising a total of \$33,164.45, HCF purchased the property on March 24, 1955.⁶³

With the addition of another anonymous donation of the same price, \$32,500.00, HCF restored the Russell House.⁶⁴ Extensive research and construction work began on

⁶⁰ Jonathan H. Poston, *The Buildings of Charleston: A Guide to the City's Architecture* (Columbia, SC: University of South Carolina Press, 1997), pg. 262.

⁶¹ Ibid.

⁶² Orlando Ridout, V and Willie Graham, *An Architectural and Historical Analysis of the Nathaniel Russell House*, pg. 45.

⁶³ Orlando Ridout, V and Willie Graham, *An Architectural and Historical Analysis of the Nathaniel Russell House*, pg. 65.

⁶⁴ Ibid.

the house shortly after its purchase. Many of Charleston's most noted experts worked on the project to restore the house for presentation to the public as a house museum from the Russells' days. At a final cost of \$56,397.38, the restoration work was completed in February, 1956.⁶⁵ Some of the major changes, such as removing the Mullally family first floor addition on the southwest corner, did not fit within the initial budget constraints of the restoration and thus remained. The house opened as a museum in the same month as work was completed. The house is a prime example of Charleston's preservation dedication and initiatives.

Restoration and research on the house have continued to create an increasingly accurate narrative interpreted to the public by the house museum. The designation of the Russell House as a National Historic Landmark (NHL) occurred in 1974. HCF hired the first full-time professional curator for the house in 1981.⁶⁶ Damage during Hurricane Hugo in 1989 ranked behind other natural disasters the house had survived in the preceding 180 years. Some extensive damage did occur to the structure that required repair and remediation before the house was able to serve as a museum again.⁶⁷ Changes and modifications for public access and comfort in 2012, including HVAC upgrades and the addition of an elevator, are the most recent upgrades the house has seen. Today, the house still operates as a museum through the work and ownership of the HCF.

⁶⁵ Orlando Ridout, V and Willie Graham, *An Architectural and Historical Analysis of the Nathaniel Russell House*, pg. 68.

⁶⁶ Ibid., 70.

⁶⁷ Ibid., 70-71.

4.3 Architectural Changes – Period I to Period VII

Period I

The history of the Nathaniel Russell House is divided into periods; the first phase begins with the original construction of the house being from 1808 to 1832. A thumbnail image of Period I, south elevation and first floor plan are shown in *Image 4.5* and *4.6*. The Nathaniel Russell House is of the Neoclassical domestic architecture style. The main house consists of a brick three story rectangle structure with its long axis running east to west and a south facing half octagon mass, protruding from the center of the rectangle, on all three levels. See *Image 4.7* and *4.8* to see the East and South Elevation as it appears today. The east and west elevations are three bays wide with the east elevation facing the street front and serving as the main entrance. The north and southern facades are four bays wide with differential center bays. The half octagon on the south façade and the ornate stair hall windows on the north façade create a-typical center bay areas. The first and third levels contain six-over six wooden sash windows. The second story has nine-over-nine wooden sash windows with a sill height at floor level. The exterior façade boasts rubbed brick and stone ornamental jack arches above openings and decorative sweeps and cornice detailing. A wrought-iron balustrade promenade runs along the second story around the east and south facades. See *Image 4.9* to see the “N.R.” detailing on the East Elevation of the balustrade. Entrance to the promenade is granted through the floor length windows on the second level.

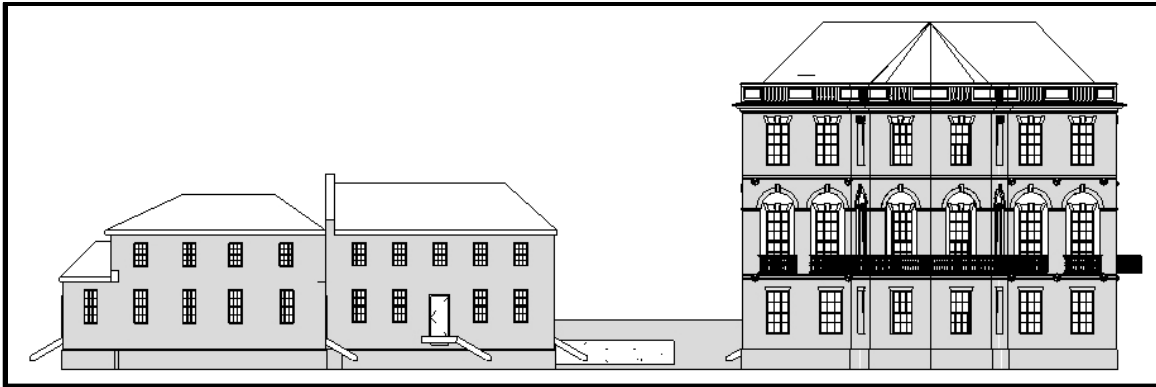


Image 4.5 The above image is the Revit-generated south elevation of the Nathaniel Russell House. Model made possible by Glenn Keyes Architects and Ridout, Orlando, V, and Willie Graham. An Architectural and Historical Analysis of the Nathaniel Russell House. Report. Vol. I. Charleston, SC: Historic Charleston Foundation, 1996.

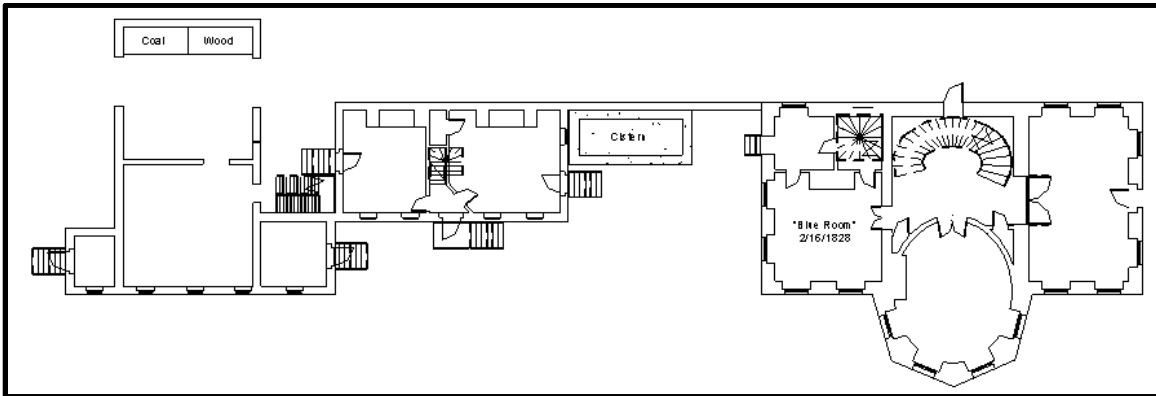


Image 4.6 The above image is the Revit-generated plan of the Nathaniel Russell House, first floor Period I. Model made possible by Glenn Keyes Architects and Ridout, Orlando, V, and Willie Graham. An Architectural and Historical Analysis of the Nathaniel Russell House. Report. Vol. I. Charleston, SC: Historic Charleston Foundation, 1996.

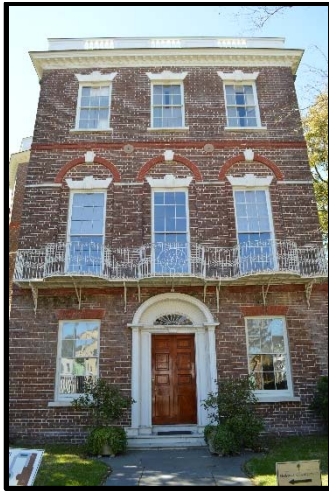


Image 4.7 The above image shows the east exterior façade of the Nathaniel Russell House. Nathaniel Russell House. Historic Charleston Foundation. Photograph by Laura Lee Worrell.



Image 4.8 The Image above shows the south exterior facade of the Nathaniel Russell House. Nathaniel Russell House. Historic Charleston Foundation. Photograph by Laura Lee Worrell.



Image 4.9 The image above shows the east front entrance architrave and second floor balustrade with Nathaniel Russell's initials in the wrought iron. Nathaniel Russell House. Historic Charleston Foundation. Photograph by Laura Lee Worrell.

The main entrance door with architrave is in the center of the east façade. Through the main entrance one enters a room the width of the house. *Image 4.10* shows the detailing of the front east entrance. The room next to the entrance room is the

staircase hall. The room occupies the central swath of the house on the north half, corresponding to the central bay of the exterior as described previously. The grand floating staircase that travels from the first to the third floor landing is one of the house's most iconic feature. See *Image 4.11* to see the staircase. At the center of the house to the south, where the half octagon protrudes on the exterior is an oval room. *Image 4.12* and *4.13* shows the restored first and second floor oval rooms. The west-most room, a mirror image in plan from the entrance room is accessed through the staircase hall. This room is square and leads to a servant or family stairwell and back entry room at the northwest corner. The servant's staircase travels from the first floor into the attic. This basic room arrangement repeats throughout all three levels of the main house. The roof is a compound hip roof with its main ridge running east to west. Three brick chimney stacks rise above the turn-metal roof.



Image 4.10 The view of the restored front east entrance room looking west with the partition wall added in 1857. Nathaniel Russell House. Historic Charleston Foundation. Photograph by Laura Lee Worrell.

A cistern yard separates the main house from the kitchen house which is only visible in the model during the first period phasing. It is an important space in understanding the house. The cistern yard is rectangle with the shorter side abutting the kitchen house west of the main house. The kitchen house is a two story brick rectangular structure with a gable end at its west and a hip roof at its east. The kitchen house stands five bays wide by two bays deep. Entrances into the structure are found at the south east corner, the center of the south elevation, and the center of the west exterior wall. A central passage linear staircase running south to north separates two square rooms at the west and east of the kitchen house. This floor plan repeats to the second level. Both rooms on each level contain one large fireplace along the center of the north wall.



Image 4.11 The above image shows the stabilized grand floating staircase of the Nathaniel Russell House looking northwest. Nathaniel Russell House. Historic Charleston Foundation. Photograph by Laura Lee Worrell.



Image 4.12 This image shows the restored first floor oval dining room looking south. Nathaniel Russell House. Historic Charleston Foundation. Photograph by Laura Lee Worrell.



***Image 4.13** The above image is of the restored second floor oval room looking westward. Nathaniel Russell House. Historic Charleston Foundation. Photograph by Laura Lee Worrell.*

The hip roof out building, believed to be a stable, is located at the western portion of the lot and connects to the kitchen house. *Image 4.14* shows the out buildings in the Revit rendering of Period II. Access between the two outbuildings is not direct, but doors into each structure are nearest one another at the south west corner of the kitchen and the northwest corner of the stable. The space between the doors of the two structures has a semi-covered open air connection with a stair case to the stable second floor. The brick tee shaped stable is two stories tall with five bays wide at its south elevation. Two small square storage rooms, one bay by one bay, located at the east and west of the structure give the T-form its arms. The west storage room is only one story tall with a hip roof. No direct access exists between these storage rooms and the main stable. Constituting the

trunk of the “T” shaped structure are a two large square rooms located to the north and south of the structure. The south room connects to the north through a single doorway. The north room has two large openings at the east and west to the outside. The north open stall room contains a coal and wood storage area at its north wall. In the second story rooms above the trunk of the “T”, an array of partition walls exist creating four potential slave quarters along an “L” shaped hallway. Architectural plans are provided in Appendix C, Plan A101-A105.

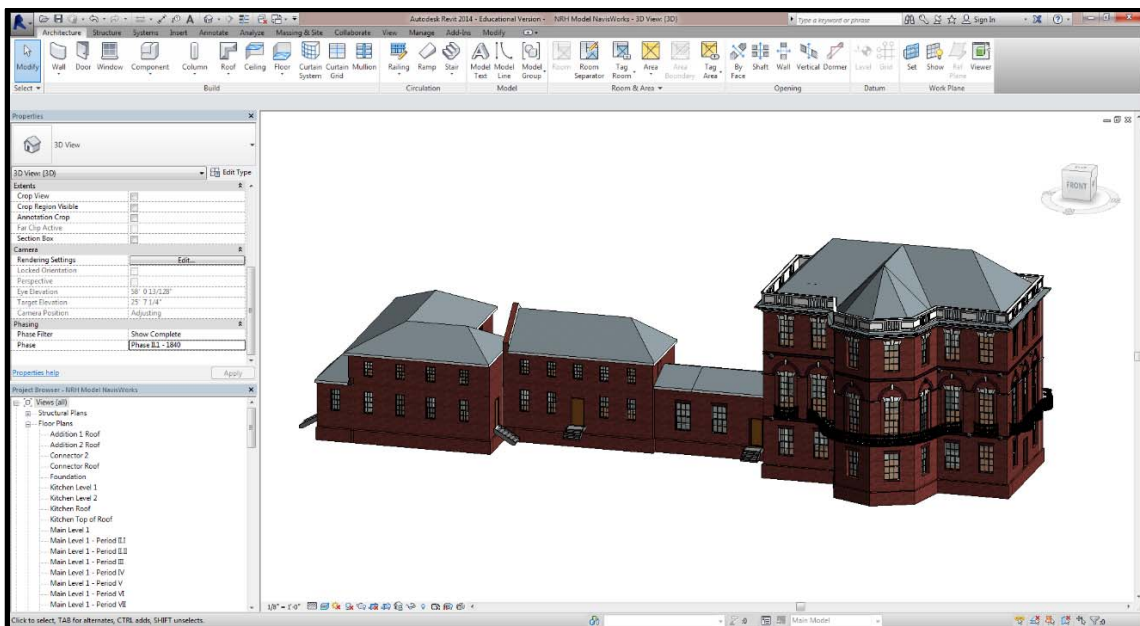


Image 4.14 The above image shows the Revit rendering of Period II with the outbuildings located to the west of the lot. Model made possible by Glenn Keyes Architects and Ridout, Orlando, V, and Willie Graham. An Architectural and Historical Analysis of the Nathaniel Russell House. Report. Vol. I. Charleston, SC: Historic Charleston Foundation, 1996.

Period II

Period Two saw changes enacted at the Nathaniel Russell House. Sarah Russell Dehon owned the house at the beginning of Period Two in 1840. She is responsible for the addition of a brick one story, three bay wide, hyphen with a gable roof over the cistern yard. The exterior doors in the addition mirror each other at the eastern most bays

on the north and south side. No windows exist along the northern wall. A second construction campaign in 1857 is part of Period Two. This campaign includes the addition of a partition wall in the “Front Room;” the partition section off a portion of the room creating a “Chamber Off Front Room” to the south. The other known addition at this time is a second level room on the 1840 hyphen connecting the kitchen to the main house. This addition has wood siding and a gable roof. It is only two bays wide and does not stretch the entire east-west width of the hyphen beneath. A brick fireplace and chimney are centered on the north wall of the second story hyphen addition. Architectural plans are provided in Appendix C, Plan A106-A111.

Period III

During Period Three, circa 1864, no major structural or architectural changes happen in the house. The difference between the two periods consists of room use changes. During Period Two, with the Dehon/Trapier family ownership, many occupants inhabited the Nathaniel Russell House. “The Backroom” defined in 1857 on the first floor, changes to the “Breakfast Room” in 1864 according to records compiled during the Historic Structures Report (HSR). The “Second Floor Front Room” in 1857 changes use to the “East Drawing Room” in 1864 and again to “Drawing Room” in 1865. Architectural plans are provided in Appendix C, Plans A112-A115.

Period IV

Period Four, defined by the ownership of the Sisters of Charity, begins circa 1870. Room use definitions change at this again with the changing function. A partition wall in the “Dining Room” extends further into the servant or informal stair case hall in the

north-west corner of the house. Kitchen utilities, sinks, and a pump show up in the kitchen house plans at this time. The one major addition is a “Covered Way” connecting the second story hyphen addition to the second floor of the kitchen house. This addition is illustrated as an exterior lattice wood material with a shed roof. A conjectural single sash fixed window appears in this connecting space. Another change in this area is the inclusion of a door way made between the west second level room of the kitchen house to the top of stair landing of the out building/stable. Lastly, on the third floor, in the north-west corner, the first “bath” appears. Architectural plans are provided in Appendix C, Plans A116-A119.

Period V

Period Five, circa 1913, under the Mullally family brings the most architectural and structural changes to the house. In the 1886 Charleston Earthquake severe damage to the out building/stable resulted in its reduction to a one-story three bay structure with two slightly varying shed roof levels and the addition of a fireplace and chimney. The earthquake also caused damage to the north wall of the hyphen which called for its rebuilding. It was rebuilt without the chimney and with the addition of a window and another door. A cellar was added under the main house, which was introduced in part to accommodate a heating furnace. An additional bay is added to the first floor “Dining Room” to the west making the room rectangle instead of its historic square shape. The “Hall” losses its’ “Reception Room” partition wall added in Period Three. The servant stair case from the first to the third floor is removed.

The second story western “Small Parlor” entrance door was relocated to a door access not previously found in the “Stairhall” closet. The construction of partition walls created a hallway through the “Small Parlor.” This division creates a “Bathroom” in 1909. The bathroom occupies the space where the servant staircase once occupied. The previous “Dressing Room” now acts as a connection to the second level hyphen room that was constructed in Period Four. The room now extends the full three bay width of the first floor of the hyphen. The hyphen gable roof is also extended the entire three bay width of the second floor. A doorway connects the second floor hyphen room to the second level of the kitchen house. The fireplace included in the original construction of the second floor hyphen room in Period Four, is removed in Period Five. Lastly, the third floor west “Bedroom” receives the same additional hallway partition walls as the room below and the east “Bedroom” closet and “Linen Closet” (1870) combine into one room as a conversion for a bathroom. Architectural plans are provided in Appendix C, Plans A120-A124.

Period VI

Period Six of the house begins with HCF’s ownership in 1955 and their restoration of the property. HVAC equipment added to the house makes the structure more comfortable for guests and helps create a more stable environment for the materials within the house. A staircase to replace the one removed in the previous periods, takes up the entire space where the side stair hall and entry hall once resided. The original staircase that still exists from the third level into the attic is shown in *Image 4.15* and the replacement staircase on all other levels can be seen in *Image 4.16*. An additional

bathroom is introduced at the top of the stairs on the second floor. HCF removes the partition walls in the south west rooms on the second floor but leaves the partition on the third floor. The addition of partitions walls in the first floor of the hyphen helps to accommodate the docents and staff of the house museum with a kitchen, staff room, and storage closets. The second floor gains office space and a bathroom during the renovations. In the Kitchen House, the original entry staircase and interior stairwell change. The Kitchen House also has exterior doors punched through the north wall on the first floor. The remaining one-story out building/stable has partition walls added to create bathrooms and storage. Architectural plans are provided in Appendix C, Plans A125-A128.



Image 4.15 The image above shows the original service staircase configuration that still exists leading from the third level to the attic. Nathaniel Russell House. Historic Charleston Foundation. Photograph by Laura Lee Worrell.



Image 4.16 The image shows the new staircase added in place of the previous winding service staircase. Today this is the main staircase used by tourists. This image looks down from the third level through the stairwell. Nathaniel Russell House. Historic Charleston Foundation. Photograph by Laura Lee Worrell.

Period VII

The ongoing efforts of architectural investigation and restoration sponsored by HCF are the continuation of Period Six. The most recent renovation and restoration in 2012 marks Period Seven of the house's history. The addition of an elevator from the first to second floor in the hyphen enables guests with mobility restrictions to visit. Restoration of the west "Blue Room" (1826) occurs during this period including blind windows on the west wall to recreate the original layout of the main house. *Image 4.17* shows the mirrored blind windows installed during restoration work. The one story addition and hyphen receive a renovation to create a designated gift shop and greeting area for visitors and guests. *Image 4.18* shows the gift shop as it appears today. An additional staircase leading to the hyphen's second level grants access to the exhibit space above. The partition for the "Chamber Off the Front Room" is restored to its original 1857 appearance. Major HVAC and system upgrades also take place during this period. Moisture and crack monitoring of the house is introduced to treat any problem or hazardous issues. Currently the third floor and attic space of the main house are not accessible to the public and have not undergone extensive restoration. These spaces are under monitoring to detect for any problematic issues or deterioration. Architectural plans are provided on the following pages, Plans A129-A132.



Image 4.17 The image above shows the blind window installed on the west wall for restoration. Nathaniel Russell House. Historic Charleston Foundation. Photograph by Laura Lee Worrell.



Image 4.18 The image above shows the remodeled hyphen, now the gift shop, looking northwest. Photo courtesy of HCF. Nathaniel Russell House. Historic Charleston Foundation. Photograph by Laura Lee Worrell.

4.4 Methodology

This section of the case study includes an abridged version of Chapters 2 and 3 of this thesis outlining the documentation, management practices, and the methodology development. The case study is divided into four major components: The first required the organization of the house's documentation and management files; the second required modeling the structure in AutoDesk Revit as a "working" model; the third utilized AutoDesk Navisworks as the user-interface for information retrieval; and finally, preservation professionals tested the model for applicability and usefulness.

Step 1

Preservation profession contacts at Historic Charleston Foundation (HCF), suggested the Nathaniel Russell House as the case study subject. A compilation of the architectural and maintenance documentation on the Russell House provided all the necessary data needed for the BIM model. As built drawings jump started the modeling process allowing the field measurement recordings to be bypassed. The Historic Structures Report (HSR) performed in 1996 contained the most useful historic data retrieved through the files. The best organized maintenance files on the house only contained tasks from 2011 to 2015. Due to the time constraints and perimeters of the case study, ten action items found within the house's documentation were chosen for modeling in conjunction. The selection process was coordinated with the Properties' Coordinator, Will Hamilton. The ten selected action items were thought of as two groups; the historical data and the management tasks. The development of an excel worksheet helped to organize the supplemental documentation files.

Step 2

AutoDesk Revit software is the model platform for this case study. The intention of only using one program manufacturer is to help address the complexity of BIM by only needing to have knowledge of one software type instead of multiple. Autodesk introduced its first software, AutoCAD, in 1982 and has led the industry in 3D design, engineering and entertainment software since its inception. Today, AutoDesk has over ninety different software's available through purchase or free.⁶⁸ The company's presence within the industry is, for the foreseeable future, not in danger of dissipating. Revit allows the modeling of the structure and Navisworks includes applications to aid in documentation and management of the resource. Plug-in software's are also available to add into Navisworks for differing needs. These plug-ins can always be included at a later date if necessary or desired but is not a priority for this case study.

As a means to demonstrate the historical data documentation ability of the model, modeling all major periods of change for the house is the important first step in Autodesk Revit. The HSR supplied drawings throughout the first five major periods of the house. Glenn Keyes Architects and Whole Building Systems furnished additional drawings for the last two major periods, Period VI – Period VII. Accuracy to one-eighth of an inch is a requirement of the Historic American Building Surveys (HABS) documentation process and is captured in the provided existing drawings. The two-dimensional drawings were linked in Revit to allow for faster modeling without having to take hand or field measurements of the house.

⁶⁸ Autodesk, Inc., "Company," Autodesk, 2015, section goes here, accessed February 22, 2015, <http://usa.autodesk.com/company/>.

The modeling of each phase happened first in the creation of the BIM model, in sequential order. The intention of the model is to act as a “working model.” This means that the model was not done in exact detail of the structure. Instead, place holders for elements such as interior doors or decorative trim were placed in the model. The location of the element is exact but the detailing is generic. Some basic topography was included to get the house context within the property lot. Meeting Street was shown as well as the path walk ways in the south of the lot’s yard. The “working model” is intended to provide a holistic model of the structure. Levels of detail can be incorporated in an incremental way. As documentation data and maintenance tasks are performed on the structure, the elements effected by new information can be created in Revit’s family creator to a higher level of detail and added to the “working model.” This method of incremental specifications intends to address potential monetary, time, knowledge, and man power limits. Large resources are needed to create a BIM model. A phased approach may be more realistic given what owner’s have available to invest in a model and management documentation system.

After modeling all of the major architectural features of the seven described periods of the structure and some topography, modeling additional detail for the ten selected elements commenced. The Nathaniel Russell House-specific elements are not available in the existing Revit element library. The Revit process of creating new model elements through existing templates helped to create the ten highly detailed elements.

After all ten elements were modeled, the generic place-holder elements were replaced with the newly created elements into their correct locations within the

structure's model. To prepare the model for the next component of the case study, each period phase in the Revit model was exported and named accordingly as a Navisworks Cache (NWC) file.

Step 3

Each Navisworks Cache (NWC) file was “appended” into a master Navisworks file and saved as a Navisworks “working file” (NWF). To prevent the duplication of model elements, the appended cache files were merged in the Navisworks working file. Cache files are utilized because they enable the different phases to be brought into Navisworks from Revit. They also will show any changes or additions in the original source file, the Revit model, without having to reload or recreate a new Navisworks file.

After each period of major changes is merged within the Navisworks file, the attachment of the historical and maintenance data was performed. This data attachment occurred through two different means. The first method intends to act as the quick access data retrieval method. The information included in the columns of the excel sheet created for the ten selected elements is added manually to the properties dialogue box of its perspective item. In the Navisworks interface this information includes the item title, construction date, cost, last work performed date, and a maintenance schedule to name a few. By adding information to this properties dialogue box, a user can click on the architectural element and see the basic information pertaining to that element.

The second method for documentation attachment utilized the external link feature in Navisworks. Similar to the hyperlink function found in Microsoft Word or Excel, external links to URL webpages or document folders can be attached to the

element in Navisworks. This feature creates a quick access link to larger external files and documentation on the element. Through the use of hyperlinks a user could click on an architectural element of interest, then on a link that pulls up a pdf file. For example, this link could contain a report that pertains to work done on the specific element. With basic information in the property dialogue box and hyperlink information attached to the ten trial elements, the model becomes interactive and serves as a portal to other management documentation.

Step 4

To determine the applicability and usefulness of the model, it was tested by a variety of preservation professionals. The testing sequence consisted of three phases. First, the test subjects were given ten minutes to navigate and familiarize themselves with the model interface in Navisworks Freedom. This is the free version of Navisworks that makes the model viewable but not editable. This platform was used instead of Navisworks Manage, the program version that requires paying for the licensing and is editable, to help address potential monetary limitations of historic resource owners.

After working in the model, the test participants were asked to complete three tasks. These tasks were meant to simulate actual working scenarios that an owner or building coordinator may need to find quickly. The different tasks asked the navigator to find elements within the model space and locate the quick access information as well as information residing in the external link documentation.

After the first two phases of testing the model were completed, a short open-ended questionnaire was presented verbally to the participants. To help gauge the success

of the model for documentation and management purposes for the historic resource, getting feedback from the testing participants was critical. The survey opened by asking the general impressions and expectations of the model. For further research benefits, participants were asked what applications or information was missing from the model that they would like to see. Lastly, the participants' overall feelings of benefits and downfalls about using this type of documentation and management methods finished the survey.

4.5 Case Study Findings

Revit

Modeling new and historic structures in BIM is not new. In this case study the intent was to take the model a step further to not only develop the model of a historic structure but to have it act as the user-interface for a management repository. The model creator has moderate experience with Revit, the modeling software used. It is important to note that the model creator is not a Revit or Navisworks expert. Issues discovered during the modeling process will be discussed later in this chapter. These issue may have arisen due to limitations in the modeler's knowledge or may be attributed to program capabilities. Revit and Navisworks contain a seemingly infinite number of capabilities but if the program user does not know how to implement the abilities of the program correctly, capabilities can be lost. Since the program was created for new construction, its capacity to accurately and efficiently model historic construction practices and materials were not robust. Some of the specific examples of these situations are discussed later in this chapter.

Walking through the process familiar from the methodology chapter, now allows for elaboration on the findings through all three phases of the model development, management documentation incorporation, and user accessibility testing. The first step in the modeling process involved the organization and naming of the different relevant family types. This was difficult due to the changing methods used to model some of the more difficult aspects of the Nathaniel Russell House, for example, the oval room that is discussed later. This issue required consistency of the modeler. Once one modeling

method for a component was discarded for another technique, unrequired family types were deleted from the family tree to prevent duplication of types and to reduce the clutter and confusion of unneeded types appearing in the software. This issue was completely modeler based. Development of individual familiarity with the process or clearly articulated best practices would resolve this problem.

A Revit software based restriction is the material options available. The Nathaniel Russell House, for example, has Flemish bond brick work. This is not a standard material for Revit. The material type had to be created to accurately represent the structure's appearance. Revit does allow the creation of a new material types. The difficult part in creating the Flemish bond material type was setting the surface pattern. Some small amount of code writing was required to create this material which can be a daunting step for those that do not know this aspect of computer programming. The solution for this challenge was found by utilizing help in online Revit forums and delving into the sample coding language. Many example pattern codes were available and explained to help with this step. Because Revit modeling has become popular in the construction and manufacturing industry, many downloadable family types and materials are searchable on the web. Some can be downloaded and used within a personal model without having to create a new material type. There is however, no historic based repository for Revit family types. Locating historic family types is nearly impossible at this point.

One of the most compounding issues during the modeling phase in Revit occurred at the walls and more specifically, the oval room on the south side of the main house. Multiple factors contributed to this issue. First, figuring out how to create the recessed

portion of the walls at the windows and doors was difficult. Initially, a multitude of varying stacked thickness walls were used to create this effect. This modeling technique lead to later issues concerning exterior brick sweep details and overall continuity of the model walls. Other issued pertained to material layer wrapping incorrectly and wall joining connections not behaving correctly.

The second attempt utilized Revit's wall stacking option. The exterior walls of the oval room were set to be overly thick. Void extrusion types were utilized and joined to the walls to create the room's oval shape and the window and door recessed details throughout the house. Again, the wall material did not wrap at the inserted voids in the correct manner instead the voids cut through the wall layers, regardless of the wall property settings. Even this work-around method of wall construction in the model did not prevent issues with the wall sweeps and reveals wrapping around desired details, specifically the exterior arch details on the second level.

The issues with the wall thickness variations is attributed to the programs limited capabilities with unusual connections and variations in material thicknesses. Many online resources were consulted to help with this dilemma. Online forums of Revit users and training books and web sites including Lynda.com and InfiniteSkills.com did not provide effective solutions. The training books and web sites did not solve the issue specifically. These sources only provided instruction on setting the type properties and understanding how to create new family types and nesting families.⁶⁹ The only available help the online forums offered was the suggestion of using void forms to create desired effect. No direct

⁶⁹ Nesting families is a term in Revit when one family type is "nested" or dependent on the family type to which it is applied to but is not editable through the nested host family type.

answers were available on how to address the wall sweep and reveal issues. The forum discussions did confirm that Revit has a lot of issues when it comes to applying sweeps and reveals, specifically when embedded in stacked walls, in the model.

Discovered during the creation of the oval room, the main staircase, and the decorative wrought-iron balustrade, Revit does not allow the construction of types based on elliptical geometry. Instead the ellipse features had to be created using differing circle diameters resulting in a less accurate shape. This modeling restriction was again not answered in the printed and online resources but through online forums. There were suggestions for multi-step processes to help with the issue. One forum user suggested utilizing the massing option to create the surface for a wall to be placed on. While this method did work, it took many trial-and-error attempts to get all the wall joins, connections, and cuts to behave in the correct visual manner.

Exterior walls of the Nathaniel Russell House range in width from over four feet at ground level to one-foot-eleven-inches at the second and third floor levels of the main house. Recessed portions of the walls exist where the doors and windows are cut through. Windows and doors are automatically placed at the wall center line in Revit. For the Nathaniel Russell House, the windows and doors are consistently six-inches inset from the exterior wall, on average, on all floors. New construction is infrequently made of structural masonry and thus walls are not as thick. Because the Nathaniel Russell House walls had voids joined to them to create the window and door recessed areas, the window and door family types defaulted to the center line of the entire wall thickness instead of being able to be placed at a specific depth within the thin wall in the overall window

openings. The type properties of the stock library types did not allow for adjustment of this parameter. Six-over-six or nine-over-nine wooden sash windows were also not available. New window family types were created with a wall depth parameter to correct this modeling issue.

The creation of new family types was also a difficult task. The online resources and purchased books on Revit did help with learning how to properly create new families. Even with the instructional videos, each family type took time to develop. The desired changeable parameters needed to be planned before modeling began, however. The order of object creation also impacted the modeling of new family types. For the windows, the frame needed to be defined first, then the sashes, mullion, and glass panes. If the sash size parameter changes, the mullion and glass panes need to flex along with it to be effective. To become proficient at creating new family types, practice and trial-and-error are key.

One of the last modeled elements was the roof. Even when it appeared that all requirements for building the roof were correct, Revit would not “finish” the family type. Revit would not show any specific error message, just that the roof could not be modeled. Through research online, this seems to be a common issue. The fix was to find a means that would trick Revit into finishing the family type. For this model, a flat roof was created just above the top of the wall. Once this was complete, the type was selected and edited to create the roof shape needed and the elevation changed.

Another issue with the roof arose when modeling the roof connection to the decorative cornice work. Revit only allows a select type of rafter cuts for the roof edge.

At the National Russell House the cornice work and the roof die straight into one another. No rafter cut option created this appearance. No void or cut geometry was allowed to effect the rafter ridge; a restriction in the program design. A sweep element with duplicated material type had to be developed to continue at the rafter edge to create the desired appearance.

One of the major components of the model was creating modifications over time that correspond to the major period phases of the house's history. If a wall was deconstructed at one phase and put back in in another, the corner connection join of the new wall and the existing wall did not always model correctly. This fix required going back to the initial phase of the walls existence to ensure the proper join that would allow for a clean cut in the right direction during later phasing.

Creating the Nathaniel Russell House working model represented in this case study took 280 hours. Issues and man hours required during the Revit modeling phase can be remedied with a more proficient Revit expert modeler and future Revit software updates. Autodesk could look into correcting flaws known to exist in the Revit software, as well as by being proactive and adding elements to help model historic structures. Even with the issues encountered, the model has many benefits. Revit provides instant drawings and plans of the house. Because many contractors and architects now utilize Revit, their work can be added easily into the model without needing a model to be developed. This can drastically help cut down on construction and design costs for new projects. This case study recognizes but does not investigate the significant potential the model holds as an educational, interpretive, and curatorial tool.

Navisworks

Transferring the phases into Navisworks took multiple attempts. At first each phase in its entirety was saved as a cache file and appended into Navisworks. Even after merging the different files, it was discovered during the Timeliner phase, that some of the types still duplicated in the model. The search set criteria had to be defined by phase and by demolition or by construction. This created extra unplanned tasks within the Timeliner simulation but it did not negatively affect the simulation.

During the data assignment and linking phase in Navisworks additional issues presented. The identity data input on the types in Revit appeared in various different property dialogue tabs in Navisworks. For this reason, a new tab, specific to historic and management information, was created in the properties box for the architectural element. This step is more time consuming because each line and column of information must be input manually one at a time. The more information desired in this dialogue box, the more time consuming data entry will be.

Linking external documents and URLs was not problematic. However, some of the restrictions within the program did hinder the usefulness of this capability. Icons showing the links available within the model can have their visual representation turned off or on. If zoomed to see the entire model, link icons can clutter the model field making it difficult to see the model. The “show link” icon is best only turned on if the building component is zoomed into. Also, the link option does not allow linking to file folders, only individual files. Due to this restriction and not wanting to attach multiple links to

each object, a Drop Box account was created specifically for this model with the organized files. URL addresses to the objects file folder were attached instead of each individual file. The same effect could have been achieved by utilizing a Microsoft Excel or Word document with links to external file documents organized within the source file. Drop Box was utilized because it is a financially effective way to store digital documents and data. Business accounts can be created with one-terabyte of storage for a small fee per month. The historic resource owner would not have to spend funds on business servers or maintenance and all files are backed-up in case of unforeseen issues. Other options such as Google+ accounts exists that offer similar services.

After the Timeliner application was applied to show the building periods and the documentation data was associated with its correlating objects in the model, the file was saved as a Navisworks published file, NWD. Navisworks Freedom is used as the free program to allow the access to the model for documentation and management purposes. One of the unfortunate limitations to using the Freedom version of the program is that it does not allow any updates. Within Freedom, linking additional files or folders and adding information into the documentation and management properties tab is not difficult. Model users can easily be instructed how to do these tasks and would benefit greatly if some edit capabilities were possible. This way slight errors or new information could be added upon discovery easily. Developing this complete step of the case study BIM application required significantly less man hours than the Revit implementation only taking 24 hours. This time frame does not include the commitment invested during step one that includes the research and organized documentation.

Benefits in utilizing Navisworks include curation and education, scheduling and cost, and access to documentation and management files. Navisworks allows the creation of animations videos and fly-throughs to show the structure and its attributes. This can benefit curation decisions and offer educational and visual aids to the public visiting the museum. Navisworks allows building components to be connected to a schedule and cost. This can create animations of building and renovation work that tracks the cost along with the work being performed. This can act as a helpful tool when envisioning additions or changes and well as for budgeting. Finally, the capability of having one repository and user-interface for data and documental retrieval creates more beneficial and useful working conditions.

Testing

The completed model and user-interface was presented to test participants using Navisworks Freedom freeware installed on a personal laptop computer. A short demonstration of the models capabilities and software format was introduced to the participants. They were allotted time to navigate and explore the model before being presented with the testing scenarios. Scenario time completion was not tracked. Because every user's experience and abilities are different, it was left up to the participant to gauge their comfort and ease of use within the model.

The participant's self-evaluation of comfort level before testing ranged from terrible to good. The participants were not asked their comfort level before beginning the model scenarios but after completing them. This was done as a preventative measure to reduce any anxiety or predetermined skill hindrances the participants might feel. After,

all separately agreed that using the model was much simpler than they had expected. The biggest issue encountered with the model usage was the navigation tools in the model. The comparison between Google Sketchup's navigation capabilities and Navisworks was made. It was noted that there is a steep learning curve with grasping the navigational tools but once that were to be mastered, the model is straight forward.

According to pre and post testing interviews, expectations of the model were exceeded for all participants. Visual appearances, data input and accessibility, and potential uses were the three noted "exceeds expectation" categories mentioned. One participant stated that basic geometrical shapes were expected instead of the model's texture and the real-life visual appearances of the structure's materials. One aspect of the appearance that participants felt should be added at a later stage in the modeling process was to have more of a contextual placement within the landscape and neighborhood.

Participants wished to see additional function capabilities of the model. A calendar notification system was suggested. The suggestion outlined a way to input maintenance schedules and inspections into a calendar and have notifications appear to alert the owners when work is scheduled to be done. This would help to budget from year to year by having a mechanism that shows anticipated work scheduled for the entire year.

Lastly, the participants were asked to share their opinions of the models foreseeable benefits and downfalls. Participants enjoyed the intuitive nature of the model interface and having all the information accessible within one platform. There was no need to search through file cabinets and folders. In addition to the documentation and

management ease for the owners, the interpretive applications that could be derived from the model were extremely intriguing to all four participants.

As for the downfalls of the model, only one individual mentioned cost as a potential deterrent. The dependency on that specific program was expressed as a concern as well as the reliance for model and data updates by a third party if staff within the organization did not invest in learning the program. Participants stated disappointment in the fact that the free Navisworks version did not allow data updates or edits. Questions arose as to if who, if any, Revit and Navisworks professionals exist in the local Charleston area or if long distance outsourcing would be necessary. Overall feelings of test participants state that having a modeling expert in-office would be better after initial model creation than continuing outsourcing for model updates.

The enthusiasm for BIM modeling of historic resources exists. As more preservationists and historic resource owners become educated on the capabilities of BIM, the driving force to fix problematic issues within the software that were discovered during this case study can be addressed. The same situation occurred within the design and construction fields that now spear head the development and use of the software. Software programmers create the applications and the industry experts using the software relay their needs and corrections for software updates so that it can be more useful tool in their arsenal.

4.6 Analysis and Conclusion

BIM has become a major asset in the construction industry for renovations, new construction, clash detection, energy audits, and facilities management. BIMs applications for historic resources has just begun to be explored. The National BIM Standard-United States™ (NBIM-US™) is working to establish “standards and infrastructure... to capture, organize, distribute, and mine [the] information” produced in a BIM model.⁷⁰ No official standard methods or best practices have yet to be completed and implemented. The procedures and methods described and utilized for this case study were developed in conjunction with personal experience and knowledge of the software and its capabilities and consulted informal and formal resources.

The intent was to create a usable model in the most simple manner possible. By limiting the different programs, the complexity of a model presented in BIM can be reduced into a manageable resource for novice users, specifically historic resource owners. The two major draw backs of the Revit model can be summarized as operator knowledge and software limitations. Revit is a vast software with a multitude of available applications and work-flow options. Having a professional expert in Revit model the historic resource can greatly increase the accuracy and detailing within the model space. Many of the problematic issues found during the modeling process could be remedied by having a better knowledge base of the software’s applications and procedures which may be known by an expert or may require the development from specific historic

⁷⁰ National Institute of Building Sciences, "About the National BIM Standard-United States™," About the National BIM Standard-United States, 2015, section goes here, accessed February 22, 2015, <http://www.nationalbimstandard.org/about.php>.

preservation experience. Many experts are still learning the best means and methods for the program's use. Those who work exclusively with the software discover flaws within the software coding and applications. Problematic issues of the program create the needs for help forums online. Through the knowledge gained from help forums and user feedback, software programmers make update corrections and add applications. After new software updates, tasks and work flow procedures can change and be greatly improved. New applications and options within the program have to be learned and perfected after software updates happen, creating an ever evolving entity in itself.

If the software developer, AutoDesk, sees industry potential within the historic resource field, additional features and software updates may be added specifically to accomplish this feat. Revit is intended to build new construction components and elements which do not necessarily translate easily to historic building practices. With a push for the historic resource application, library specific types can also be developed and made available for this modeling application. The ability to have the model contain default historical building components and accommodate historic assembly types and methods could greatly decrease the cost and time spent to develop models of historic resources.

Many of the same draw backs and potential benefits relevant to Revit also correspond to Navisworks. Software user knowledge can greatly improve the usefulness of the model for documentation and management needs. Updates and added plug-in features can greatly improve the applicability of the software as well. Some facility management systems, known as Computerized Maintenance Management Systems

(CMMS), exist to help with the tracking and organization of these tasks to predict and track scheduling costing. The systems can be tailor-made for project or business specific needs. Research, implementation, and costs are a common factor to consider when implementing a CMMS along with a BIM model.⁷¹ The implementation of CMMS's are still an ongoing experiment in software development and compatibility. Owner and operator use and understanding is also still evolving. No standard method has been developed because the field is still new. Further, every instance within the vast fields of construction, facilities management, and historic resource management are all different depending on the application and business model. Still, the field is restricted by the type of available CMMS products. Many work within parameters for job or task specific applications that may not be able to correlate to a historic resource application. Additional case studies and research into this avenue should be explored.

The evaluation of the current model from testing participants showed promise and potential for the use of BIM in historic resource documentation and management practices. While the model did not have every feature, such as the management notification ability, the overall accessibility to the documentation was recognized as a vast improvement and superior method to the current paper file filing system. With the ability to retain on-going drawing sets of the structure and the potential as a curation and education tool, the use and benefits of the model was seen as vast to the participants. Conversation among participants illuminated that the obstacles presented by

⁷¹ Don Sapp and Dan Eckstein, "Computerized Maintenance Management Systems (CMMS)," Computerized Maintenance Management Systems (CMMS), October 23, 2014, section goes here, accessed February 22, 2015, <http://www.wbdg.org/om/cmms.php>.

implementing a BIM model, the cost, time, knowledge, and manpower, is a temporary obstacle and that BIM-based management is feasible.

Not including step one of research and data organization, the Revit and Naviswork phases took a combined 304 hours to establish a working BIM model of the historic resource. An experienced intern seeking an undergraduate degree working at fifteen dollars an hour for twelve weeks could produce an initial working BIM model. Using this scenario, a historic resource owner can begin to address some of the constraints mentioned previously that may hinder the implementation of a working BIM model with an investment or grant of \$7,200.00.

The BIM model was proven to be an effective tool for historic resource documentation and management. Implementation, time, money, and knowledge of the creation and use of the model are relevant hurdles that must be addressed when considering employing this method. The presented scenario above is just one of many that can help drive historic resource BIM implementation. Continued attempts and publications of methods used can also help drive this force because historic resource owners are excited for the potential of this application and are willing, within their means, to begin exploring and testing BIM.

CHAPTER FIVE

CONCLUSION

There is little evidence today that suggests historic resource managers have developed an effective long term plan for documenting maintenance and repairs on historic resources. The documentation and records management methods and applications that vastly improved in 1980's throughout the United States has stalled. On an international front it appears the U.S. is falling behind the European Nations, specifically England, in the adaptation and use of newer technologies for preservation. Luckily, laser scanning technologies in recent years have spurred new enthusiasm into the life and practice of preservation documentation in the States. Owners and practitioners are demanding and experimenting with point clouds. The visual products and benefits produced by the point cloud are just as captivating to the preservation field today as the visual products and benefits produced by BIM were to the design and construction industry 20 years ago. The convergence of these two technologies is already taking place and will become more and more effective and efficient in the following years. With this technology, a historic BIM (HBIM) application is the next stage in preservation advancement. This study serves as a stepping stone to further the HBIM implementation by providing a learning opportunity to help create a practical application.

A HBIM application include both pros and cons. The owner possesses comprehensive working and as-built drawings that aid in future work, decisions, and research saving time and money in the long view. Not only does the application provide digital back-ups for all archival and maintenance documents but creates a comprehensive

repository. Curation, educational, and advertising tools can be created with a model as well. These additive tools' products provide tangible and intangible benefits to visitors, owners, and investors in the form of costs, knowledge, and positive management decisions.

The four main, reoccurring constraints of BIM implementation and updates are cost, time, knowledge, and manpower. Cons for the software required as the BIM platform include digital documentation storage life and Autodesk's longevity. Revit does not provide a historic library making model creation more time consuming and costly. The linking capabilities of external documents in Navisworks to building components is not idealistic. In-program software anomalies hinder some modeling tasks, even when software updates attempt to correct them. A larger scale issue that plagues many industries and professionals, not just those in preservation and BIM development, involves the processing speed of computers. BIM software requires fast processing capabilities. The larger the file, the more processing power needed to create a more usable model.

The stewardship of preservation resources will always require historic and maintenance documentation to guide and inform best practices to ensure the survival of that resource. Unfortunately, the retention and management of this data is not always appropriately practiced even with the advent of digitizing documents. The requirement for traditional archives will always be needed. The implementation of BIM is not meant to act as a replacement to archives but a tool to more efficiently and effectively access and interpret the information, similar to how GIS advanced map making. It is assumed

that the preservation field leans toward a stance of skepticism when introducing new technologies. Through the research and case study performed, this no longer seems to be the mind set in the preservation field with respect toward documentation.

The decision to narrow the scope of the case study to historic house museums occurred in response to the questionnaire presented to industry professionals involved in preservation. A major finding from the survey concluded that the restoration, architectural, and engineering fields did not see a need for their design drawings to be developed with new software programs due to average project size and costs. The resources and time it would take to generate a HBIM model for every project would not benefit their applications. It is an application many have contemplated utilizing, however. It would be beneficial to their work if presented with an already existing model. In short, working in BIM did not suit the short time-scale of a consultant's engagement with a historic resource. When HCF, a non-profit historic house museum owner, was presented with the potential use of a HBIM application, enthusiasm and intrigue for its potential was expressed. The sustaining nature of this organization's stewardship to the resource makes the initial investment in a BIM infrastructure pay off overtime.

As a part of the best practice work flow development for the case study, it was important to consider the potential hindrances the creation and integration of a HBIM application faces for its intended audience. Again, owners of house museums and similar resources with long time investment and needs for documentation retention are the intended recipients for this application. Often these owners are non-profit organizations or small local government entities that have limitations on money, time, knowledge, and

manpower. As a means to address these issues it was determined that a “working” model would be the best option to help address many of the aforementioned constraints. This “working” and ever evolving model is also considered the “best-practice” method for historic resources because new knowledge and maintenance tasks will occur regularly and need to be integrated within the existing model. This is very similar to the implementation method conceived by Mount Vernon and staff for the HBIM application developed in 2013 for the estate discussed in chapter two.

Historic and maintenance documentation of the Nathaniel Russell House were used to create application scenarios within the model for testing by the managing staff at HCF. Because the Nathaniel Russell House has many periods of significance associated with it, the importance of being able to provide a visual representation of each period was high. The other main task to be accomplished through the use of the HBIM application is to associate data and documents with individual model elements. Autodesk’s Revit and Navisworks are utilized for the case study on the Nathaniel Russell House because of prior personal software knowledge, global industry use, and software reliability. It is easier to modify an already existing software, such as Revit, to accommodate the needs of historic resources than to create a new software application like the Dublin Institute attempted as discussed in Chapter 2.⁷² Autodesk programs already have a large community of knowledgeable experts in various professions unlike the program coding required of the Dublin Institute study. Similarly, unlike Mount Vernon’s HBIM application that utilized GIS as the mechanism for data and document attachment with its

⁷² C. Dore and M. Murphy, "Integration of HBIM and 3D GIS for Digital Heritage Modelling," proceedings of Digital Documentation, Edinburg, Scotland (2012), pg. 22-23, <http://arrow.dit.ie/beschconcon/13/>.

established expert base, Navisworks acts as that platform. The decision for BIM use over GIS stemmed from the project size, a small city lot and single house structure, instead of Mount Vernon's estate of hundreds of acres. Lastly, the testing of the final HBIM product by the HCF staff provided the most insightful data concerning the use and applicability.

As experienced modeling the Nathaniel Russell House and chronicled in the previous chapters, modeling a historic structure in Revit revealed some problematic instances. The intention of Revit is modeling for new construction applications. Historic construction practices, such as multi-wythe structural masonry walls, and historic materials, such as Flemish bond brick patterns, are difficult to model with the current software program design parameters. Objects based on ellipse geometry and irregularly angled connections must be approximated in order to accomplish within the model. These "best-fit" measures required to model a historic structure create compounding fallacies in the final model documentation resource. Remediation of most issues is possible with the development of a historic objects repository or library, similar to the new construction type library currently provided by Autodesk for Revit. With the addition of a historic based library, time required to model historic structures decreases as well as the amount of money required to model.

After the completion of the "working model," integration into the Navisworks platform began. Issues discovered include the correct workflow integration of the Revit model into Navisworks. The remediation of this issue is possible through software education to understand the appropriate file type delineation and file linking procedure. This issue is not preservation specific to the application. The attachment of data and

external documentation to objects in the model is possible but limited. Linking more than one external document to any object creates clutter and confusion within the model space during user navigation and the ability to link computer file folders is not yet possible. To remedy this current issue, two options are available. The first requires the creation of a master Excel document that contains file links pertaining to the object kept on local hard drives and servers. The second relies on web based, or cloud, data storage options such as Dropbox or Google+. By utilizing a third party service, data is consistently backed up and no server maintenance is required by the resource owner. In addition to linking external documents to model objects, a “quick access” tab created in the properties dialogue box provides basic information such as date of construction, maintenance schedule, and costs. This application was effective during model navigation trials but was time consuming to create. None of these setbacks were great enough to prevent the development of the model and accessibility to the documentation of the historic resource for end users.

BIM is the untapped potential resource needed in the preservation field for documentation and management needs. Not only does the BIM application provide owners with a much needed holistic and additive user-interface platform for historic and maintenance documentation, it is also an “interactive, digital ‘filing cabinet’” as described by Mount Vernon that can act as an educational, curative, and management tool as well. The included imagery and creative tools provide methods for video making and fly-throughs for a more interactive and engaging educational experience for visitors and outreach programs. Non-existing or expense prohibitive acquisitions and restoration work can be modeled to inform visitors of historic appearances or to aid curation and

management decisions. Restoration or remodeling work can be built into the model with cost and scheduling projections. This feature can aid the resource and its owners with funding requests or through traditional construction coordination purposes. Once the Revit model is established, any Autodesk software program can be utilized with additional software licensing from cloud-based field management applications to energy audits.

When introduced to the idea of the application, enthusiasm was prevalent but so was skepticism as to if it was actually possible within a user friendly application. Completed “working” model demonstrations and testing to historic resource owners shows that preservationists are not reluctant toward new technological aids. In fact, after allowing participants to navigate through the model, every participant’s confidence in the ease of use within the platform increased substantially. The benefits of the HBIM application seen by the participants quickly led to discussions of future budgeting possibilities and staff education for implementation.

The application use for preservation in BIM is possible and is a largely underutilized resource in the preservation field. There are issues in the software and with a non-existing best-practice work flow that currently hinders the mass spread of knowledge and use of the application within the preservation field, however. The Revit software and library was not designed for historic building practices or materials. The attachment of external documents, while possible, are not ideal at the software’s current stage of development. A desired feature suggested by historic resource owners included a calendar notification system for maintenance and budgetary outlook projects which does

not currently exist in the present platform. Even with these temporary setbacks, because the design and new construction industry now use this platform almost universally there is a large knowledgeable personnel pool that exists that can create and incorporate this application within the preservation field. Instead of developing a completely new application platform, such as in the Dublin Institute's development, the modification of an already existing and known platform can occur earlier and more easily.

If the preservation community is asking if BIM should be used for historic resources the answer is absolutely yes. The HBIM application not only acts as the primary documentation and maintenance management repository, but it also establishes a resource that can be edited and updated for the Architectural, Engineering, and Construction (AEC) industry performing any needed work on the resource. In addition to the management of the resource, an HBIM application increases the resources available for curating and public education with imagery and videos. This one application implementation grants historic resource stakeholders access to a variety of tools in one platform potentially saving time and costs.

The industries the BIM platform was developed for are continually perfecting and modifying its use and applications. Once the preservation profession learns and recognizes the vast benefits gained from a HBIM application, industries such as Autodesk will in return recognize a new market and begin tailoring preservation specific applications and object libraries. The difficulty and lengthy time it now takes to develop a documentation model of a historic versus new resource will diminish spurring even more interest from the preservation field. A cycle will be created back to the software

developer to provide updates and modifications for improvement; the same situation that is occurring in the design and new construction industry. The potential and benefits gained from a HBIM application are too great for the preservation community to forego any longer.

APPENDICES

Appendix A

Industry Profession Questionnaire

BIM – The Untapped Potential for Preservation Management and Documentation

Thesis Questionnaire
Laura Lee Worrell

I am conducting my thesis on the applicability of Building Information Modeling (BIM) for the documentation and management of historic resources, specifically in the case of house museums. I am looking to see what programs professionals use within the preservation industry and how. If BIM or other digital format programs are not being used, why? Thank you for any help or advice you can provide. I look forward to hearing your responses.

NAME: _____ COMPANY: _____

- 1.) What does your company specialize in? What is your specialty?
- 2.) Does the company you are employed with work exclusively with preservation projects? If not, what percentage of the projects are preservation related?
- 3.) Does your company use computer aided drafting (CAD) programs for projects such as AutoCAD Architecture or Revit, for example? And how are they used: for documentation, structural analysis, design?
- 4.) If CAD programs are not used, why not? Is CAD not necessary for work required at your company? Maybe your company employs one type of CAD or CAD like program instead of another because of employee based knowledge or program costs. Please feel free to give any information about how and why or why not certain programs are used.
- 5.) How do you store the majority of your completed documentation? Hard copy or digitally? Has this been a reliable method in your experience?
- 6.) Are you or your company involved in any organizations or groups concerning BIM? What is the entities purpose and your role within them?
- 7.) Have you or your company performed test or prototype projects to see if BIM could work for you? If so what did it involve and include? What were the end results?
- 8.) If your company manages house museums, what methods do you use to manage them?
(*Person based knowledge, Excel, Paper Files, etc.*)

Appendix B

Model Testing Agenda

AGENDA

February 11, 2015

Model Testing – HCF Personnel

Introduction

The detailing of this model is ongoing. The exterior of the model includes more detailing than the interior. All placements of doors, windows, and stairs are accurate in accordance with provided CAD drawings. The model is intended to be a working model. Elements can be added or changed out as work and documentation progress.

Intention

The intention of this exercise is to see if the information within the model is easily accessible and usable.

Tasks

5-10 Minutes

Navigate and explore around the model.

Complete Three Exercises

- (1) Locate the archaeology report of Unit N195.5 E131
- (2) How much did the faux grain painting for the East front entrance cost and who performed the work?
- (3) Find the paint analysis report performed in Room 107.

Questionnaire

Before this exercise, what did you feel your comfort level was with this type of user interface/technology? Was it easier than you thought it would be to use?

What was the most difficult thing about utilizing this model?

Where there any expectations that were not met by this model?

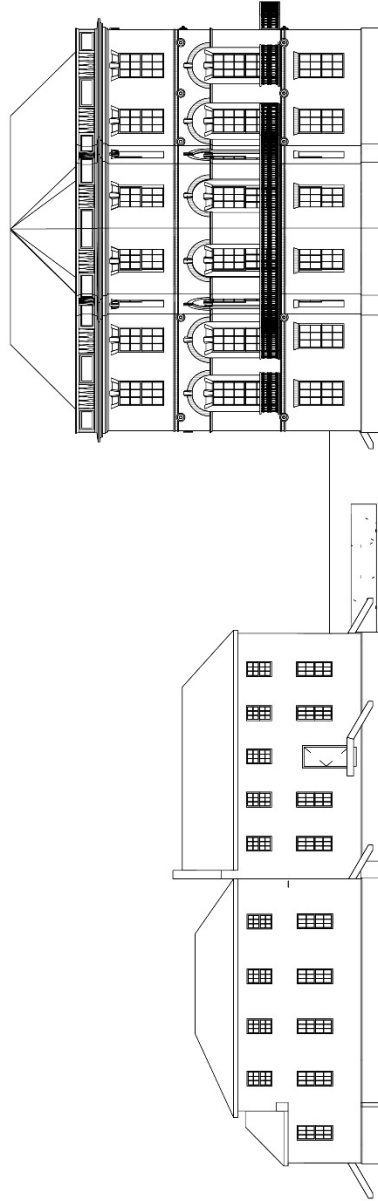
Where there any expectations that this model exceeded?

What application would you like to see added to this model?

What major benefits and/or downfalls do you see by utilizing a model like this for documentation and management of a historic resource?

Appendix C

Architectural Drawings of the Nathaniel Russell House: Period I – Period VII

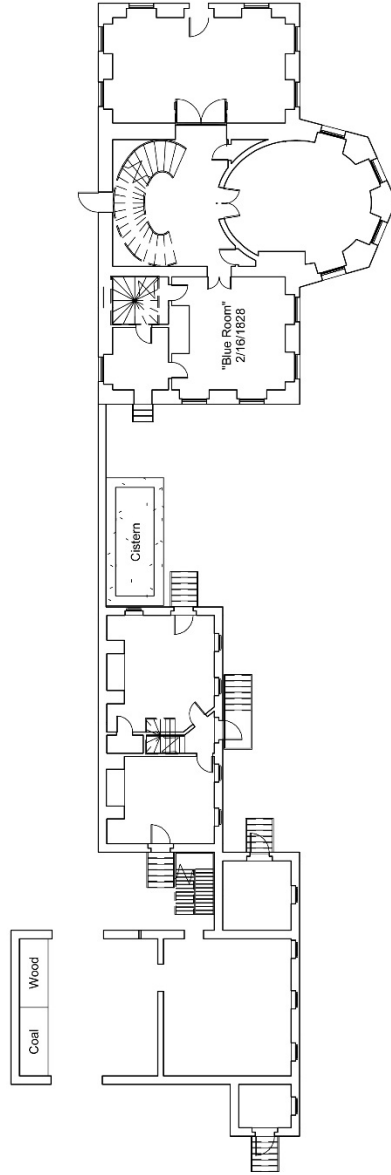


**This drawing was produced in Autodesk Revit with help from information and drawings provided by the Historic Charleston Foundation, Historic Structures Report of the Nathaniel Russell House and through drawings provided by Glenn Keyes Architects and Whole Building Systems.
 Orlando Ridout, V and Willie Graham, An Architectural and Historical Analysis of the Nathaniel Russell House, report, vol. I (Charleston, SC: Historic Charleston Foundation, 1996).

3/12/2015 1:04:09 PM

Autodesk® Revit®		Historic Charleston Foundation		PERIOD I - c. 1808-1832 - South Elevation	
www.autodesk.com/revit		Nathaniel Russell House		Project number	NRH03012015
				Date	March 23, 2015
				Drawn by	Laura Lee Worrell
				Checked by	n/a
				Scale	1" = 30'-0"

A101

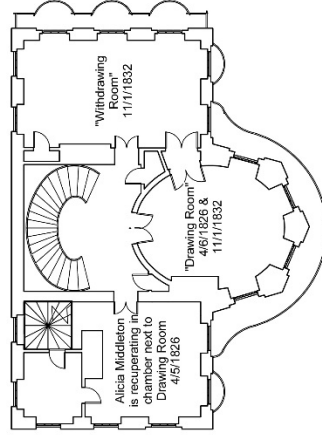
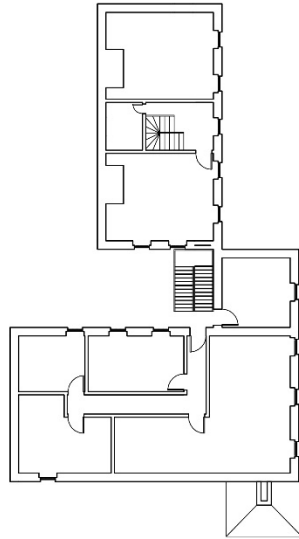


**This drawing was produced in Autodesk Revit with help from information and drawings provided by the Historic Charleston Foundation, Historic Structures Report of the Nathaniel Russell House and through drawings provided by Glenn Keyes Architects and Whole Building Systems.
 Orlando Ridout, V and Willie Graham, An Architectural and Historical Analysis of the Nathaniel Russell House, report, vol. I (Charleston, SC: Historic Charleston Foundation, 1996).

3/12/2015 1:04:18 PM

Autodesk® Revit®		Historic Charleston Foundation		PERIOD I - c. 1808-1832 - Level 1	
www.autodesk.com/revit		Nathaniel Russell House		Project number	NRH03012015
				Date	March 23, 2015
				Drawn by	Laura Lee Worrell
				Checked by	n/a
				Scale	1" = 30'-0"

A102

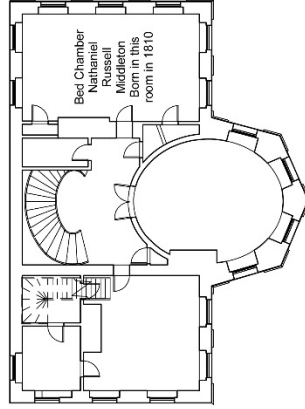
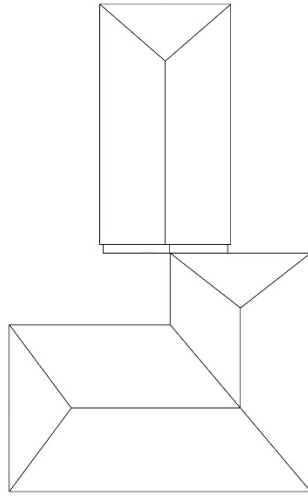


**This drawing was produced in Autodesk Revit with help from information and drawings provided by the Historic Charleston Foundation, Historic Structures Report of the Nathaniel Russell House and through drawings provided by Glenn Keyes Architects and Whole Building Systems.
 Orlando Ridout, V and Willie Graham, An Architectural and Historical Analysis of the Nathaniel Russell House, report, vol. I (Charleston, SC: Historic Charleston Foundation, 1996).

3/12/2015 1:04:22 PM

Autodesk® Revit®		Historic Charleston Foundation		PERIOD I - c. 1808-1832 - Level 2	
www.autodesk.com/revit		Nathaniel Russell House		Project number	NRH03012015
				Date	March 23, 2015
				Drawn by	Laura Lee Worrell
				Checked by	n/a
				Scale	1" = 30'-0"

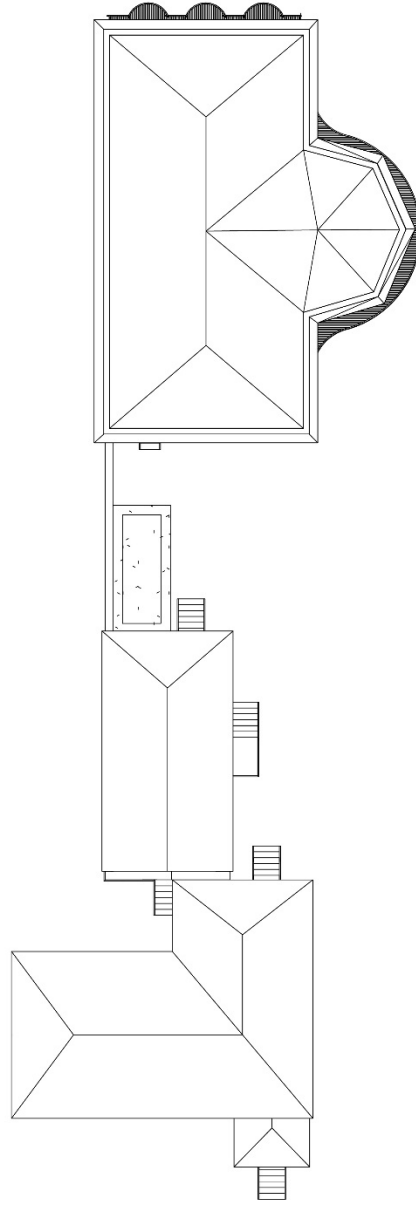
A103



**This drawing was produced in Autodesk Revit with help from information and drawings provided by the Historic Charleston Foundation, Historic Structures Report of the Nathaniel Russell House and through drawings provided by Glenn Keyes Architects and Whole Building Systems. Orlando Ridout, V and Willie Graham, An Architectural and Historical Analysis of the Nathaniel Russell House, report, vol. I (Charleston, SC: Historic Charleston Foundation, 1996).

3/12/2015 1:04:26 PM

Autodesk® Revit®		Historic Charleston Foundation		PERIOD I - c. 1808-1832 - Level 3	
www.autodesk.com/revit		Nathaniel Russell House		Project number	NRH03012015
				Date	March 23, 2015
				Drawn by	Laura Lee Worrell
				Checked by	n/a
				Scale	1" = 30'-0"
				A104	

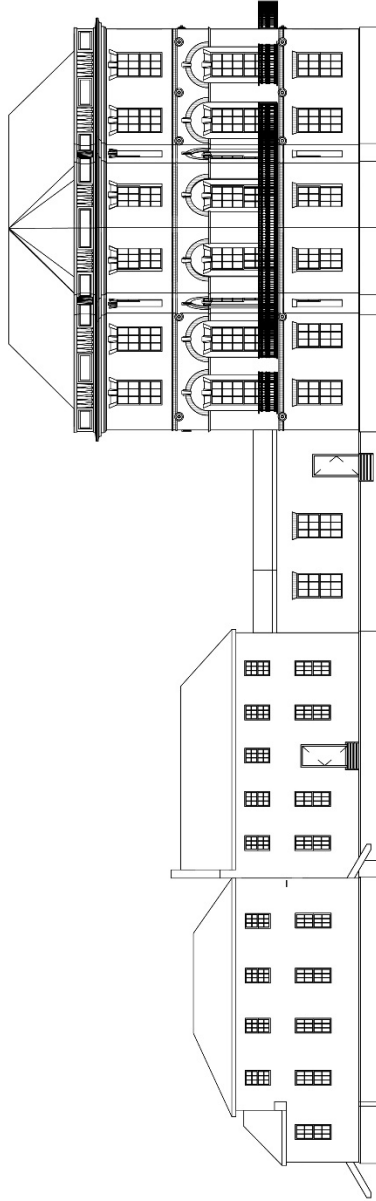


**This drawing was produced in Autodesk Revit with help from information and drawings provided by the Historic Charleston Foundation, Historic Structures Report of the Nathaniel Russell House and through drawings provided by Glenn Keyes Architects and Whole Building Systems.
 Orlando Ridout, V and Willie Graham, An Architectural and Historical Analysis of the Nathaniel Russell House, report, vol. I (Charleston, SC: Historic Charleston Foundation, 1996).

3/12/2015 1:04:29 PM

Autodesk® Revit® www.autodesk.com/revit	Historic Charleston Foundation		PERIOD I - c. 1808-1832 - Level Site	
	Nathaniel Russell House		Project number	NRH03012015
			Date	March 23, 2015
			Drawn by	Laura Lee Worrell
			Checked by	n/a
			Scale	1" = 30'-0"

A105

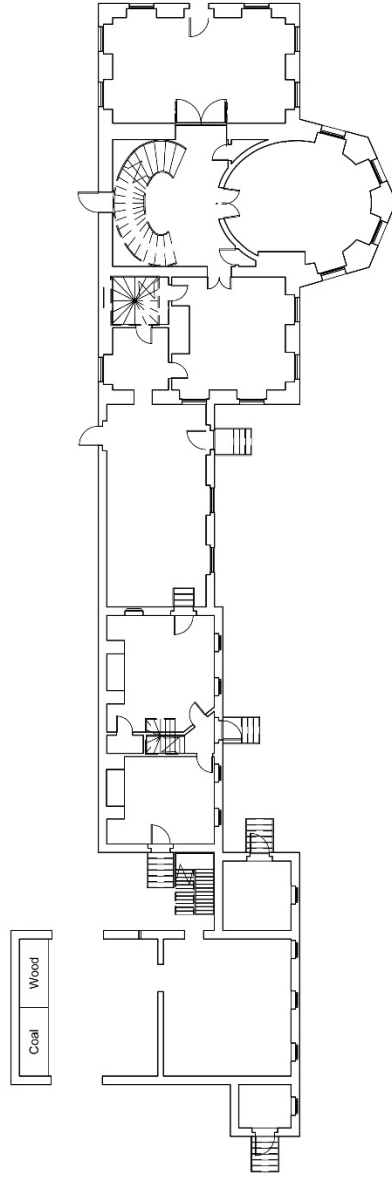


**This drawing was produced in Autodesk Revit with help from information and drawings provided by the Historic Charleston Foundation, Historic Structures Report of the Nathaniel Russell House and through drawings provided by Glenn Keyes Architects and Whole Building Systems.
 Orlando Ridout, V and Willie Graham, An Architectural and Historical Analysis of the Nathaniel Russell House, report, vol. I (Charleston, SC: Historic Charleston Foundation, 1996).

3/12/2015 1:04:46 PM

Autodesk® Revit®		Historic Charleston Foundation		PERIOD II.I - c. 1840 - South Elevation	
www.autodesk.com/revit		Nathaniel Russell House		Project number	NRH03012015
				Date	March 23, 2015
				Drawn by	Laura Lee Worrell
				Checked by	n/a
				Scale	1" = 30'-0"

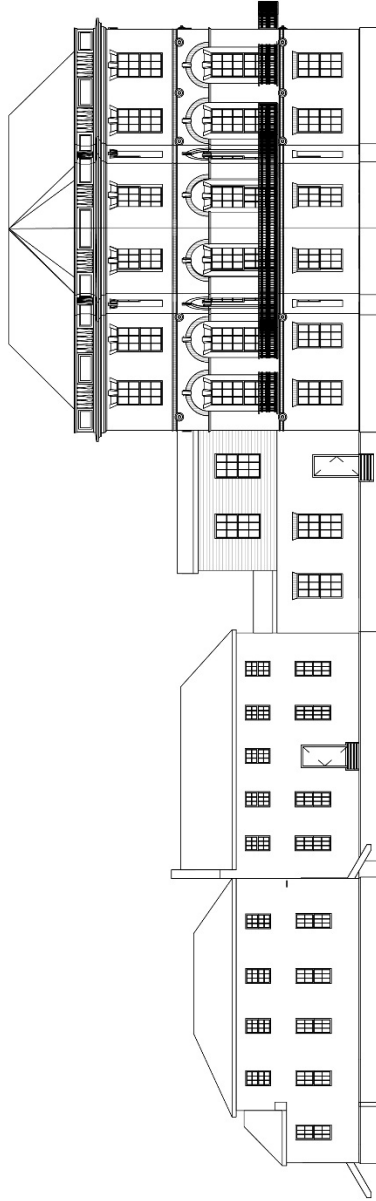
A106



**This drawing was produced in Autodesk Revit with help from information and drawings provided by the Historic Charleston Foundation, Historic Structures Report of the Nathaniel Russell House and through drawings provided by Glenn Keyes Architects and Whole Building Systems.
 Orlando Ridout, V and Willie Graham, An Architectural and Historical Analysis of the Nathaniel Russell House, report, vol. I (Charleston, SC: Historic Charleston Foundation, 1996).

3/12/2015 1:04:49 PM

Autodesk® Revit®		Historic Charleston Foundation		PERIOD II.I - c. 1840 - Level 1	
www.autodesk.com/revit		Project number	NRH03012015	A107	
		Date	March 23, 2015		
		Drawn by	Laura Lee Worrell		
		Checked by	n/a	Scale	1" = 30'-0"

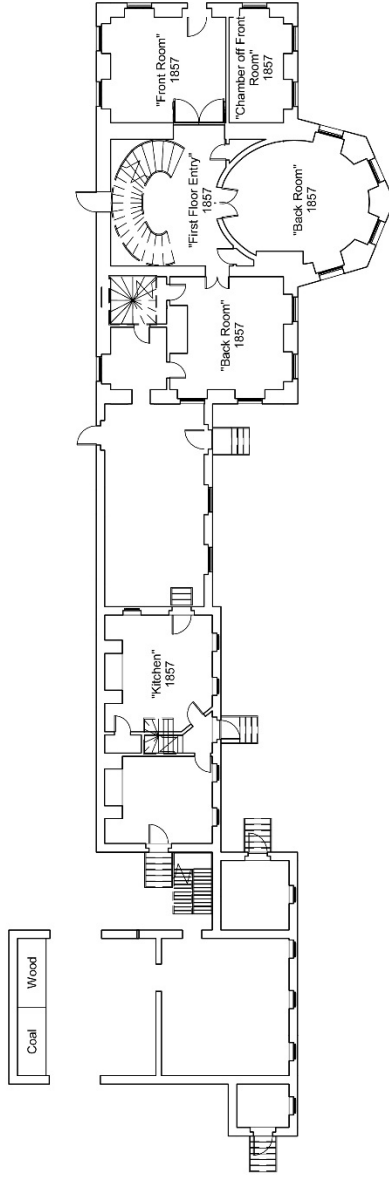


**This drawing was produced in Autodesk Revit with help from information and drawings provided by the Historic Charleston Foundation, Historic Structures Report of the Nathaniel Russell House and through drawings provided by Glenn Keyes Architects and Whole Building Systems.
 Orlando Ridout, V and Willie Graham, An Architectural and Historical Analysis of the Nathaniel Russell House, report, vol. I (Charleston, SC: Historic Charleston Foundation, 1996).

3/12/2015 1:05:20 PM

Autodesk® Revit®		Historic Charleston Foundation		PERIOD II.II - c. 1857 - South Elevation	
www.autodesk.com/revit		Nathaniel Russell House		Project number	NRH03012015
				Date	March 23, 2015
				Drawn by	Laura Lee Worrell
				Checked by	n/a
				Scale	1" = 30'-0"

A108

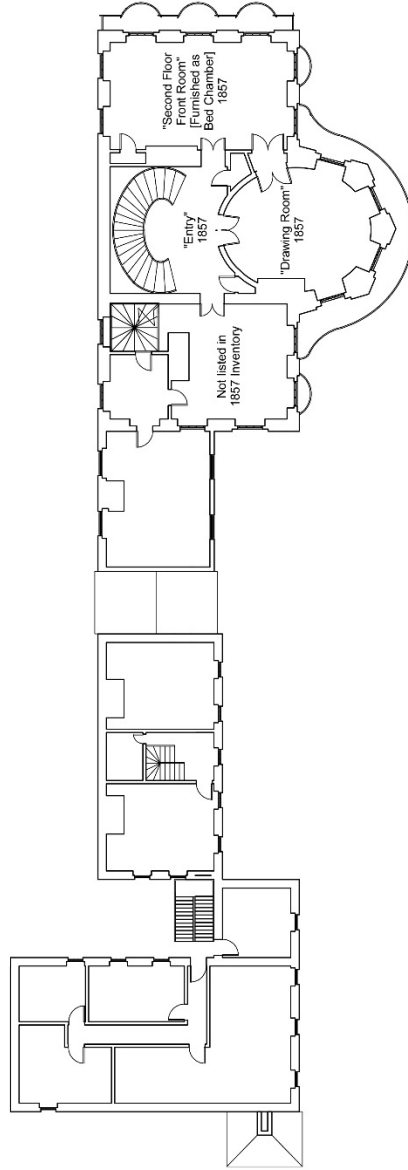


**This drawing was produced in Autodesk Revit with help from information and drawings provided by the Historic Charleston Foundation, Historic Structures Report of the Nathaniel Russell House and through drawings provided by Glenn Keyes Architects and Whole Building Systems. Orlando Ridout, V and Willie Graham, An Architectural and Historical Analysis of the Nathaniel Russell House, report, vol. I (Charleston, SC: Historic Charleston Foundation, 1996).

3/12/2015 1:05:24 PM

Autodesk® Revit®		Historic Charleston Foundation		PERIOD II.II - c. 1857 - Level 1	
www.autodesk.com/revit		Nathaniel Russell House		Project number	NRH03012015
				Date	March 23, 2015
				Drawn by	Laura Lee Worrell
				Checked by	n/a
				Scale	1" = 30'-0"

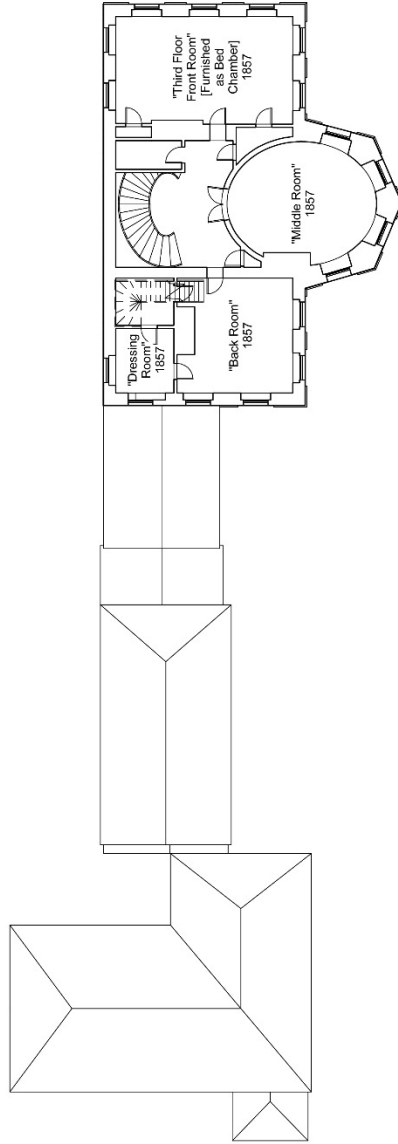
A109



3/12/2015 1:05:27 PM

**This drawing was produced in Autodesk Revit with help from information and drawings provided by the Historic Charleston Foundation, Historic Structures Report of the Nathaniel Russell House and through drawings provided by Glenn Keyes Architects and Whole Building Systems. Orlando Ridout, V and Willie Graham, An Architectural and Historical Analysis of the Nathaniel Russell House, report, vol. I (Charleston, SC: Historic Charleston Foundation, 1996).

Autodesk® Revit®		Historic Charleston Foundation		PERIOD II.II - c. 1857 - Level 2	
www.autodesk.com/revit		Nathaniel Russell House		Project number	NRH03012015
				Date	March 23, 2015
				Drawn by	Laura Lee Worrell
				Checked by	n/a
				Scale	1" = 30'-0"

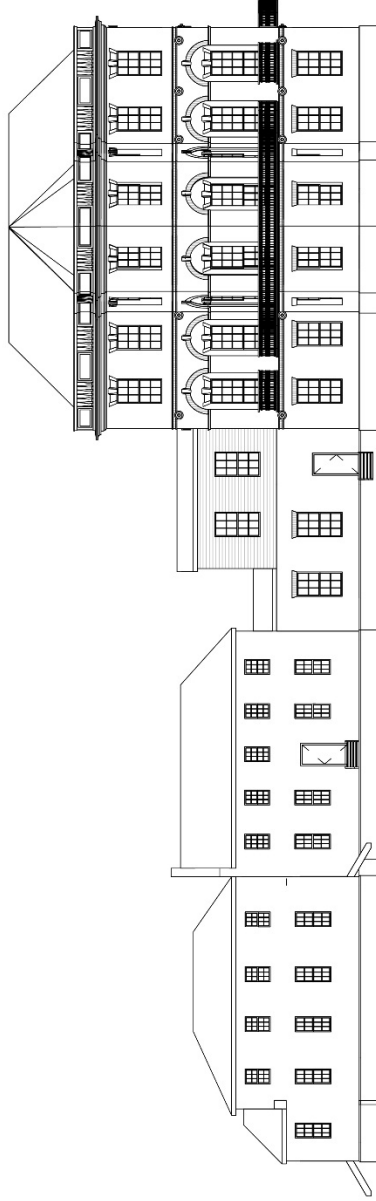


**This drawing was produced in Autodesk Revit with help from information and drawings provided by the Historic Charleston Foundation, Historic Structures Report of the Nathaniel Russell House and through drawings provided by Glenn Keyes Architects and Whole Building Systems.
 Orlando Ridout, V and Willie Graham, An Architectural and Historical Analysis of the Nathaniel Russell House, report, vol. I (Charleston, SC: Historic Charleston Foundation, 1996).

3/12/2015 1:05:28 PM

Autodesk® Revit®		Historic Charleston Foundation		PERIOD II.II - c. 1857 - Level 3	
www.autodesk.com/revit		Nathaniel Russell House		Project number	NRH03012015
				Date	March 23, 2015
				Drawn by	Laura Lee Worrell
				Checked by	n/a
				Scale	1" = 30'-0"

A111

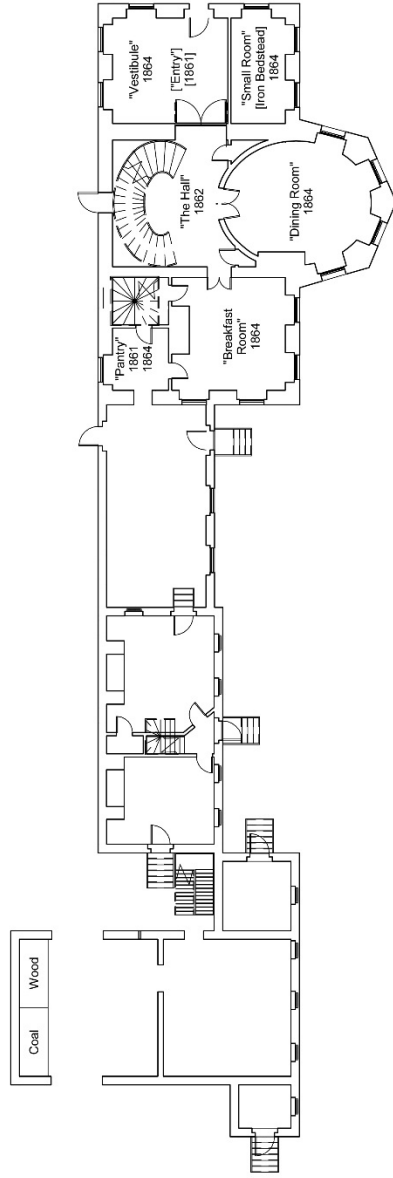


**This drawing was produced in Autodesk Revit with help from information and drawings provided by the Historic Charleston Foundation, Historic Structures Report of the Nathaniel Russell House and through drawings provided by Glenn Keyes Architects and Whole Building Systems.
 Orlando Ridout, V and Willie Graham, An Architectural and Historical Analysis of the Nathaniel Russell House, report, vol. I (Charleston, SC: Historic Charleston Foundation, 1996).

3/12/2015 1:05:45 PM

Autodesk® Revit®		Historic Charleston Foundation		PERIOD III - c. 1864 - South Elevation	
www.autodesk.com/revit		Nathaniel Russell House		Project number	NRH03012015
				Date	March 23, 2015
				Drawn by	Author
				Checked by	Checker
				Scale 1" = 30'-0"	

A112

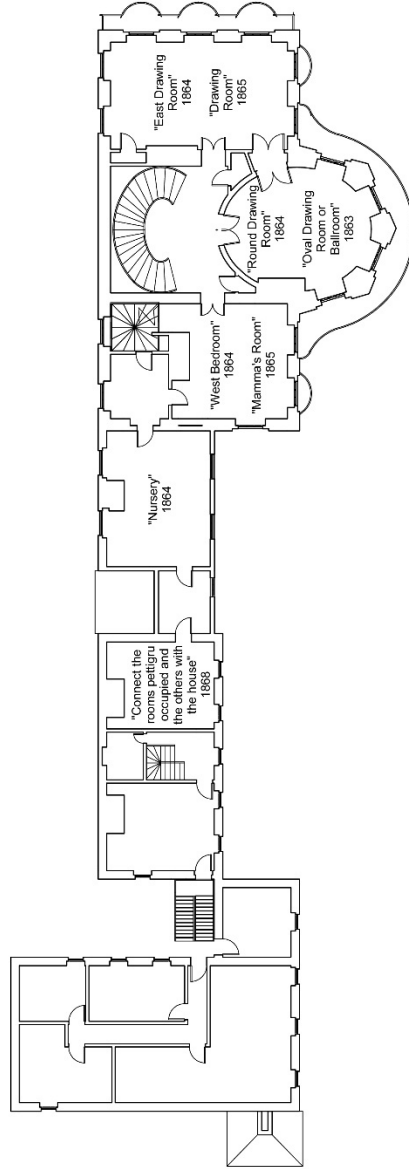


3/12/2015 1:05:48 PM

**This drawing was produced in Autodesk Revit with help from information and drawings provided by the Historic Charleston Foundation, Historic Structures Report of the Nathaniel Russell House and through drawings provided by Glenn Keyes Architects and Whole Building Systems. Orlando Ridout, V and Willie Graham, An Architectural and Historical Analysis of the Nathaniel Russell House, report, vol. I (Charleston, SC: Historic Charleston Foundation, 1996).

Autodesk® Revit® www.autodesk.com/revit	Historic Charleston Foundation		PERIOD III - c. 1864 - Level 1	
	Nathaniel Russell House		Project number	NRH03012015
			Date	March 23, 2015
			Drawn by	Laura Lee Worrell
			Checked by	n/a
			Scale	1" = 30'-0"

A113

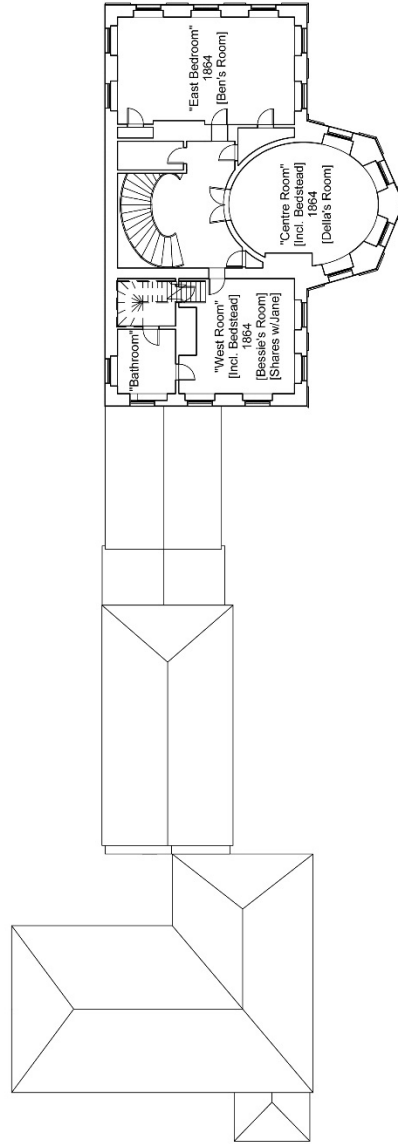


**This drawing was produced in Autodesk Revit with help from information and drawings provided by the Historic Charleston Foundation, Historic Structures Report of the Nathaniel Russell House and through drawings provided by Glenn Keyes Architects and Whole Building Systems. Orlando Ridout, V and Willie Graham, An Architectural and Historical Analysis of the Nathaniel Russell House, report, vol. I (Charleston, SC: Historic Charleston Foundation, 1996).

3/12/2015 1:05:50 PM

Autodesk® Revit®		Historic Charleston Foundation		PERIOD III - c. 1864 - Level 2	
www.autodesk.com/revit		Nathaniel Russell House		Project number	NRH03012015
				Date	March 23, 2015
				Drawn by	Laura Lee Worrell
				Checked by	n/a
				Scale	1" = 30'-0"

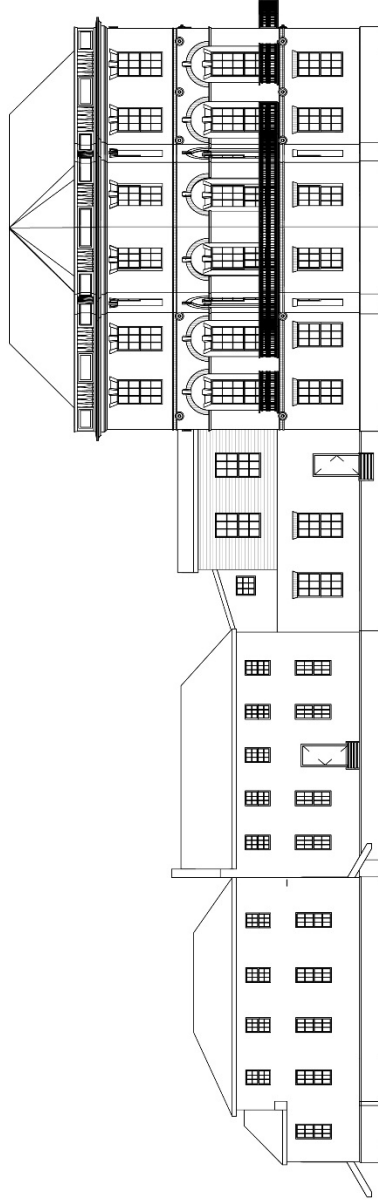
A114



3/12/2015 1:05:52 PM

**This drawing was produced in Autodesk Revit with help from information and drawings provided by the Historic Charleston Foundation, Historic Structures Report of the Nathaniel Russell House and through drawings provided by Glenn Keyes Architects and Whole Building Systems. Orlando Ridout, V and Willie Graham, An Architectural and Historical Analysis of the Nathaniel Russell House, report, vol. I (Charleston, SC: Historic Charleston Foundation, 1996).

Autodesk® Revit®		Historic Charleston Foundation		PERIOD III - c. 1864 - Level 3	
www.autodesk.com/revit		Nathaniel Russell House		Project number	NRH03012015
				Date	March 23, 2015
				Drawn by	Laura Lee Worrell
				Checked by	n/a
				Scale	1" = 30'-0"

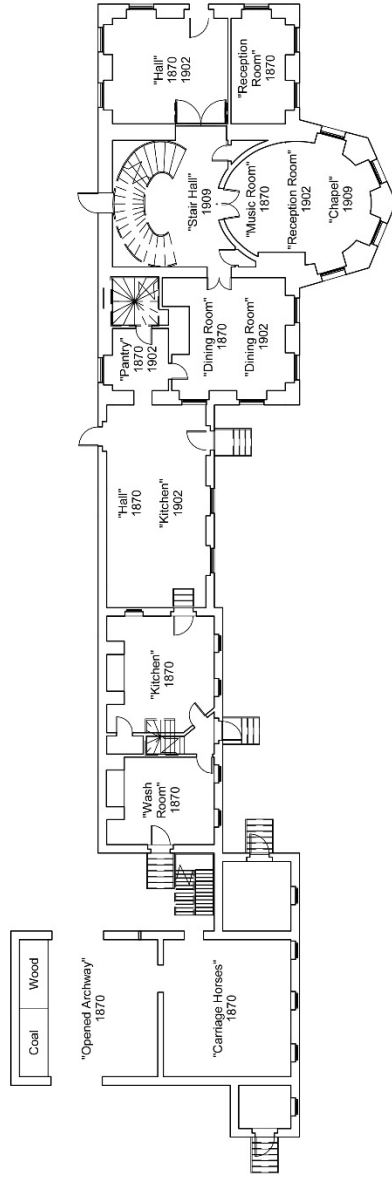


**This drawing was produced in Autodesk Revit with help from information and drawings provided by the Historic Charleston Foundation, Historic Structures Report of the Nathaniel Russell House and through drawings provided by Glenn Keyes Architects and Whole Building Systems.
 Orlando Ridout, V and Willie Graham, An Architectural and Historical Analysis of the Nathaniel Russell House, report, vol. I (Charleston, SC: Historic Charleston Foundation, 1996).

3/12/2015 1:06:08 PM

Autodesk® Revit®		Historic Charleston Foundation		PERIOD IV - c. 1870 - South Elevation	
www.autodesk.com/revit		Nathaniel Russell House		Project number	NRH03012015
				Date	March 23, 2015
				Drawn by	Laura Lee Worrell
				Checked by	n/a
				Scale	1" = 30'-0"

A116

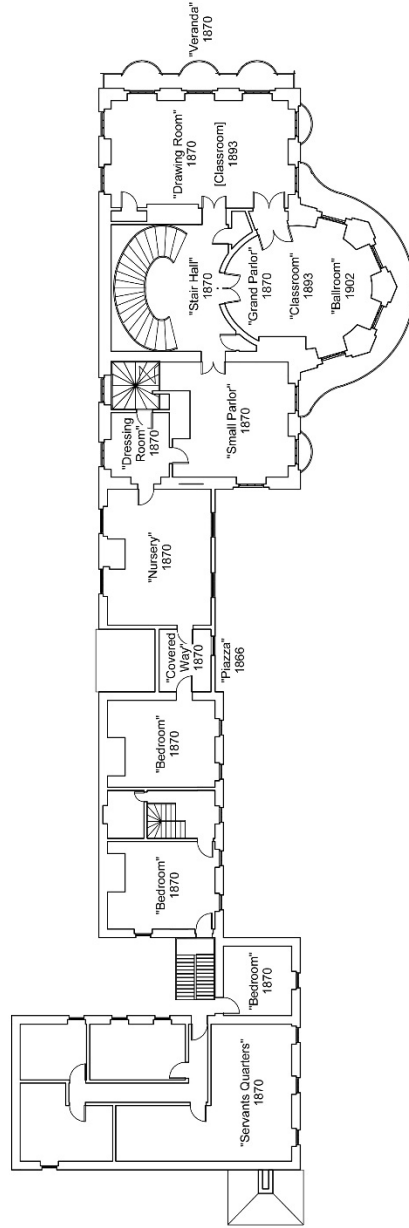


**This drawing was produced in Autodesk Revit with help from information and drawings provided by the Historic Charleston Foundation, Historic Structures Report of the Nathaniel Russell House and through drawings provided by Glenn Keyes Architects and Whole Building Systems. Orlando Ridout, V and Willie Graham, An Architectural and Historical Analysis of the Nathaniel Russell House, report, vol. I (Charleston, SC: Historic Charleston Foundation, 1996).

3/12/2015 1:06:12 PM

Autodesk® Revit®		Historic Charleston Foundation		PERIOD IV - c. 1870 - Level 1	
www.autodesk.com/revit		Nathaniel Russell House		Project number	NRH03012015
				Date	March 23, 2015
				Drawn by	Laura Lee Worrell
				Checked by	n/a
				Scale	1" = 30'-0"

A117

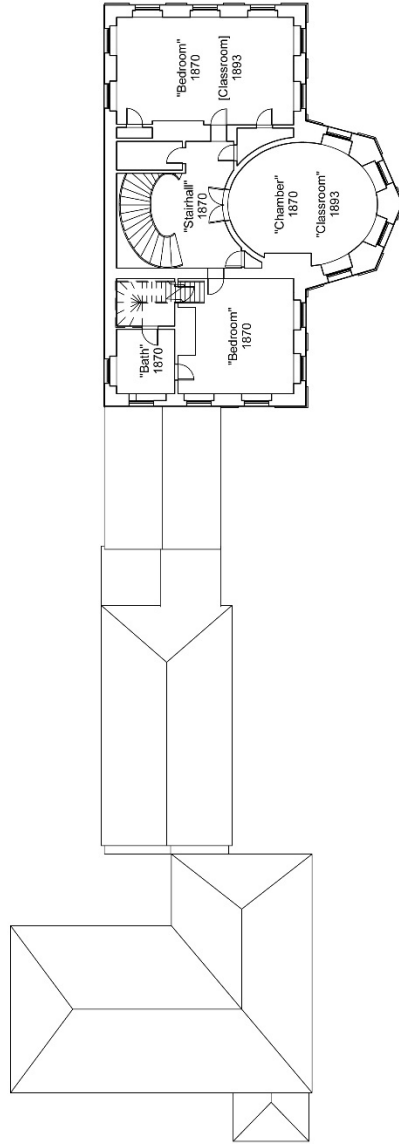


**This drawing was produced in Autodesk Revit with help from information and drawings provided by the Historic Charleston Foundation, Historic Structures Report of the Nathaniel Russell House and through drawings provided by Glenn Keyes Architects and Whole Building Systems.
 Orlando Ridout, V and Willie Graham, An Architectural and Historical Analysis of the Nathaniel Russell House, report, vol. I (Charleston, SC: Historic Charleston Foundation, 1996).

3/12/2015 1:06:14 PM

Autodesk® Revit®		Historic Charleston Foundation		PERIOD IV - c. 1870 - Level 2	
www.autodesk.com/revit		Nathaniel Russell House		Project number	NRH03012015
				Date	March 23, 2015
				Drawn by	Laura Lee Worrell
				Checked by	n/a
				Scale	1" = 30'-0"

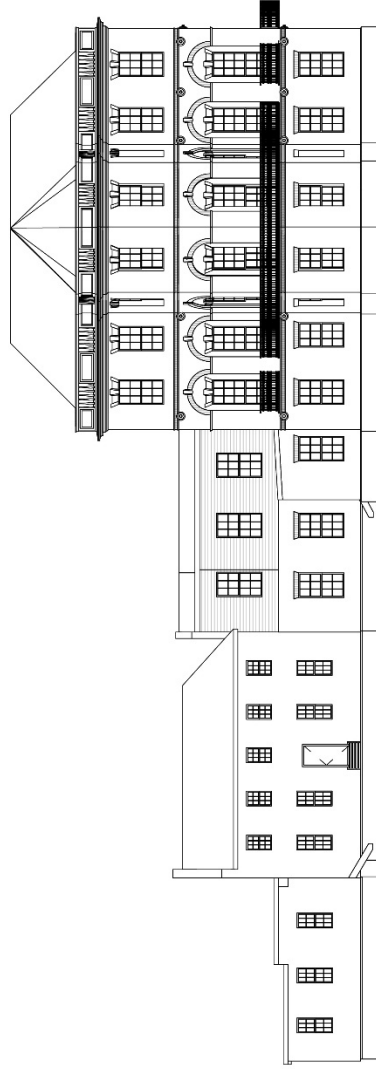
A118



**This drawing was produced in Autodesk Revit with help from information and drawings provided by the Historic Charleston Foundation, Historic Structures Report of the Nathaniel Russell House and through drawings provided by Glenn Keyes Architects and Whole Building Systems.
 Orlando Ridout, V and Willie Graham, An Architectural and Historical Analysis of the Nathaniel Russell House, report, vol. I (Charleston, SC: Historic Charleston Foundation, 1996).

3/12/2015 1:06:16 PM

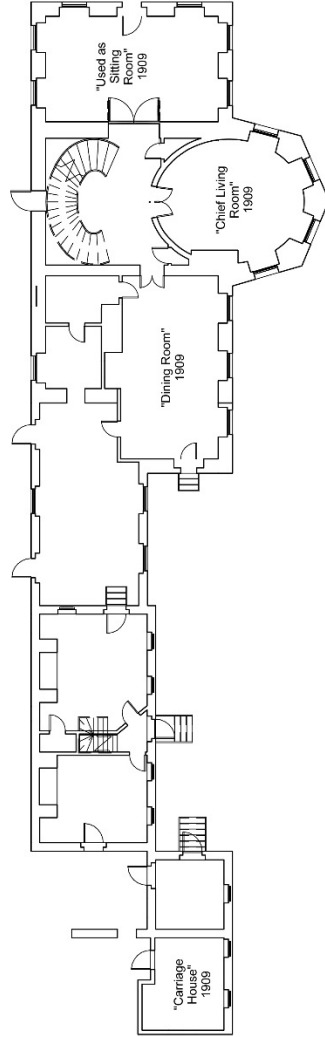
Autodesk® Revit®		Historic Charleston Foundation		PERIOD IV - c. 1870 - Level 3	
www.autodesk.com/revit		Nathaniel Russell House		Project number	NRH03012015
				Date	March 23, 2015
				Drawn by	Laura Lee Worrell
				Checked by	n/a
				Scale	1" = 30'-0"
				A119	



**This drawing was produced in Autodesk Revit with help from information and drawings provided by the Historic Charleston Foundation, Historic Structures Report of the Nathaniel Russell House and through drawings provided by Glenn Keyes Architects and Whole Building Systems.
 Orlando Ridout, V and Willie Graham, An Architectural and Historical Analysis of the Nathaniel Russell House, report, vol. I (Charleston, SC: Historic Charleston Foundation, 1996).

3/12/2015 1:06:34 PM

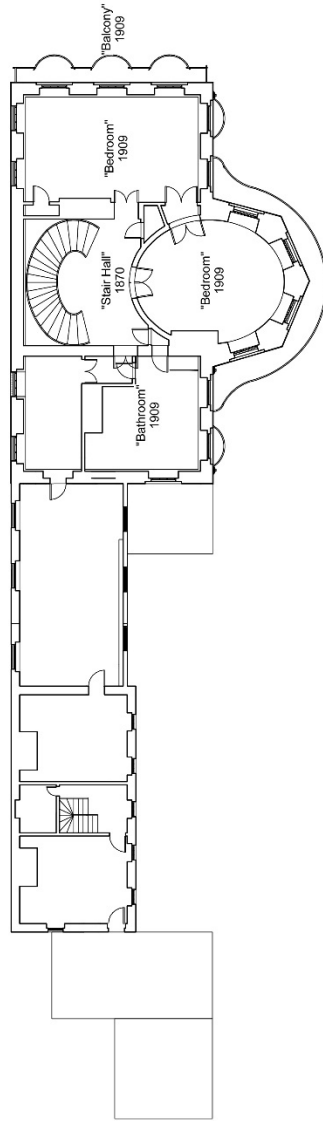
Autodesk® Revit®		Historic Charleston Foundation		PERIOD V - c. 1913 - South Elevation	
www.autodesk.com/revit		Project number	NRH03012015	A120	
		Date	March 23, 2015		
		Drawn by	Laura Lee Worrell		
		Checked by	n/a	Scale	1" = 30'-0"



**This drawing was produced in Autodesk Revit with help from information and drawings provided by the Historic Charleston Foundation, Historic Structures Report of the Nathaniel Russell House and through drawings provided by Glenn Keyes Architects and Whole Building Systems. Orlando Ridout, V and Willie Graham, An Architectural and Historical Analysis of the Nathaniel Russell House, report, vol. I (Charleston, SC: Historic Charleston Foundation, 1996).

3/12/2015 1:06:37 PM

Autodesk® Revit®	Historic Charleston Foundation			
	Nathaniel Russell House			
www.autodesk.com/revit	PERIOD V - c. 1913 - Level 1			
	Project number	NRH03012015	A121	
	Date	March 23, 2015		
	Drawn by	Laura Lee Worrell		
Checked by		n/a	Scale	1" = 30'-0"

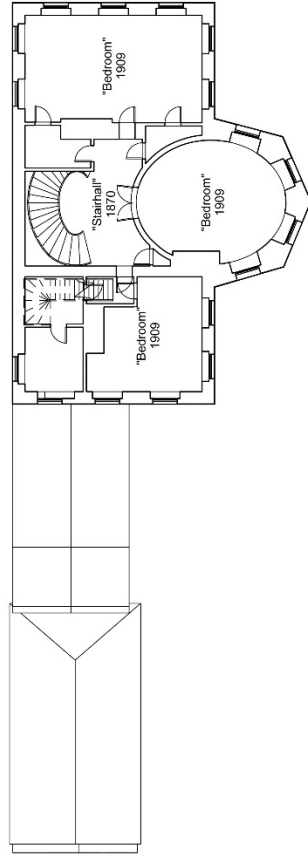


**This drawing was produced in Autodesk Revit with help from information and drawings provided by the Historic Charleston Foundation, Historic Structures Report of the Nathaniel Russell House and through drawings provided by Glenn Keyes Architects and Whole Building Systems.
 Orlando Ridout, V and Willie Graham, An Architectural and Historical Analysis of the Nathaniel Russell House, report, vol. I (Charleston, SC: Historic Charleston Foundation, 1996).

3/12/2015 1:06:41 PM

Autodesk® Revit®		Historic Charleston Foundation		PERIOD V - c. 1913 - Level 2	
www.autodesk.com/revit		Nathaniel Russell House		Project number	NRH03012015
				Date	March 23, 2015
				Drawn by	Laura Lee Worrell
				Checked by	n/a
				Scale	1" = 30'-0"

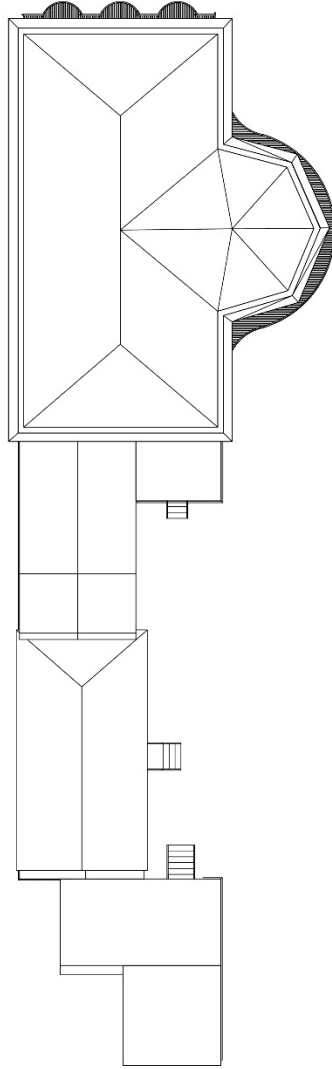
A122



**This drawing was produced in Autodesk Revit with help from information and drawings provided by the Historic Charleston Foundation, Historic Structures Report of the Nathaniel Russell House and through drawings provided by Glenn Keyes Architects and Whole Building Systems.
Orlando Ridout, V and Willie Graham, An Architectural and Historical Analysis of the Nathaniel Russell House, report, vol. I (Charleston, SC: Historic Charleston Foundation, 1996).

3/12/2015 1:06:43 PM

Autodesk® Revit® www.autodesk.com/revit	Historic Charleston Foundation		PERIOD V - c. 1913 - Level 3	
	Project number	NRH03012015	A123	
	Date	March 23, 2015		
	Drawn by	Laura Lee Worrell		
	Checked by	n/a	Scale	1" = 30'-0"

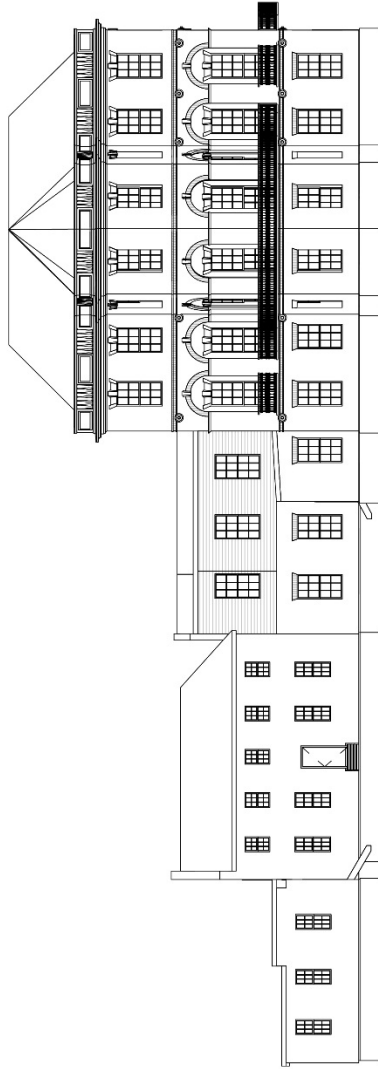


**This drawing was produced in Autodesk Revit with help from information and drawings provided by the Historic Charleston Foundation, Historic Structures Report of the Nathaniel Russell House and through drawings provided by Glenn Keyes Architects and Whole Building Systems.
 Orlando Ridout, V and Willie Graham, An Architectural and Historical Analysis of the Nathaniel Russell House, report, vol. I (Charleston, SC: Historic Charleston Foundation, 1996).

3/12/2015 1:06:47 PM

Autodesk® Revit®		Historic Charleston Foundation		PERIOD V - c. 1913 - Level Site	
www.autodesk.com/revit		Nathaniel Russell House		Project number	NRH03012015
				Date	March 23, 2015
				Drawn by	Laura Lee Worrell
				Checked by	n/a
				Scale	1" = 30'-0"

A124

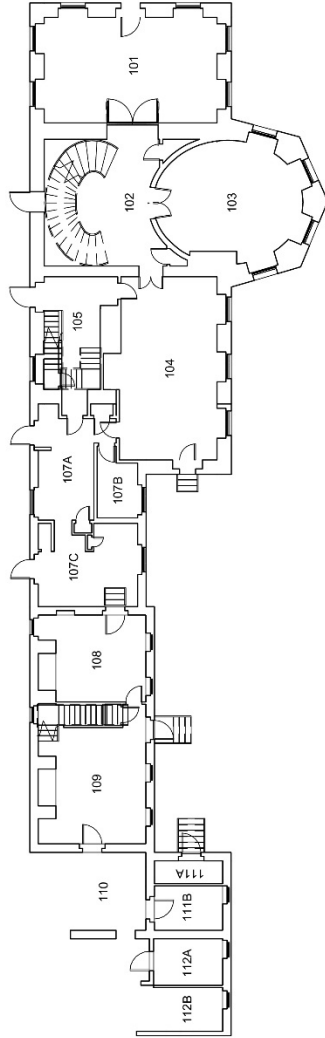


**This drawing was produced in Autodesk Revit with help from information and drawings provided by the Historic Charleston Foundation, Historic Structures Report of the Nathaniel Russell House and through drawings provided by Glenn Keyes Architects and Whole Building Systems.
 Orlando Ridout, V and Willie Graham, An Architectural and Historical Analysis of the Nathaniel Russell House, report, vol. I (Charleston, SC: Historic Charleston Foundation, 1996).

3/12/2015 1:07:06 PM

Autodesk® Revit®		Historic Charleston Foundation		PERIOD VI - c. 1956 - South Elevation	
www.autodesk.com/revit		Nathaniel Russell House		Project number	NRH03012015
				Date	March 23, 2015
				Drawn by	Laura Lee Worrell
				Checked by	n/a
				Scale	1" = 30'-0"

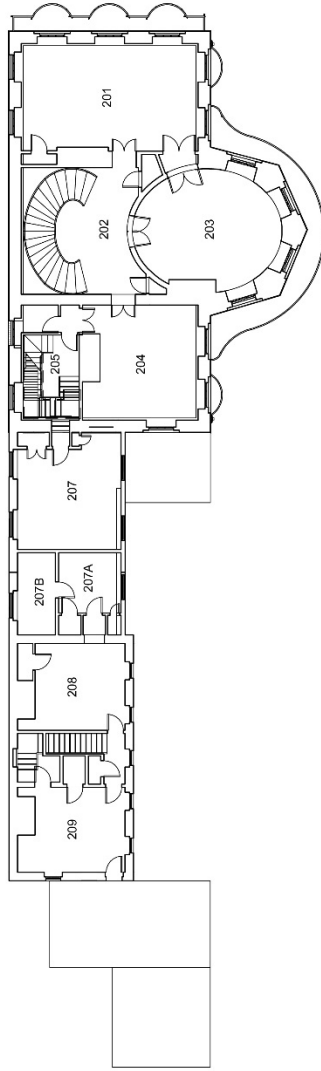
A125



3/12/2015 1:07:10 PM

**This drawing was produced in Autodesk Revit with help from information and drawings provided by the Historic Charleston Foundation, Historic Structures Report of the Nathaniel Russell House and through drawings provided by Glenn Keyes Architects and Whole Building Systems. Orlando Ridout, V and Willie Graham, An Architectural and Historical Analysis of the Nathaniel Russell House, report, vol. I (Charleston, SC: Historic Charleston Foundation, 1996).

Autodesk® Revit®		Historic Charleston Foundation		PERIOD VI - c. 1956 - Level 1	
www.autodesk.com/revit		Project number	NRH03012015	A126	
		Date	March 23, 2015		
		Drawn by	Laura Lee Worrell		
		Checked by	n/a	Scale	1" = 30'-0"

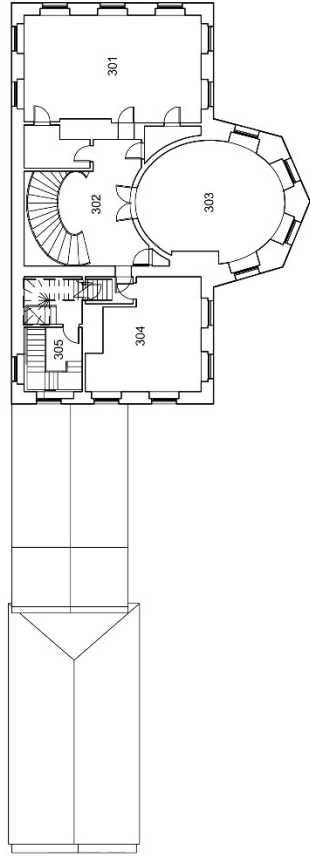


**This drawing was produced in Autodesk Revit with help from information and drawings provided by the Historic Charleston Foundation, Historic Structures Report of the Nathaniel Russell House and through drawings provided by Glenn Keyes Architects and Whole Building Systems.
 Orlando Ridout, V and Willie Graham, An Architectural and Historical Analysis of the Nathaniel Russell House, report, vol. I (Charleston, SC: Historic Charleston Foundation, 1996).

3/12/2015 1:07:13 PM

Autodesk® Revit®		Historic Charleston Foundation		PERIOD VI - c. 1956 - Level 2	
www.autodesk.com/revit		Nathaniel Russell House		Project number	NRH03012015
				Date	March 23, 2015
				Drawn by	Laura Lee Worrell
				Checked by	n/a
				Scale	1" = 30'-0"

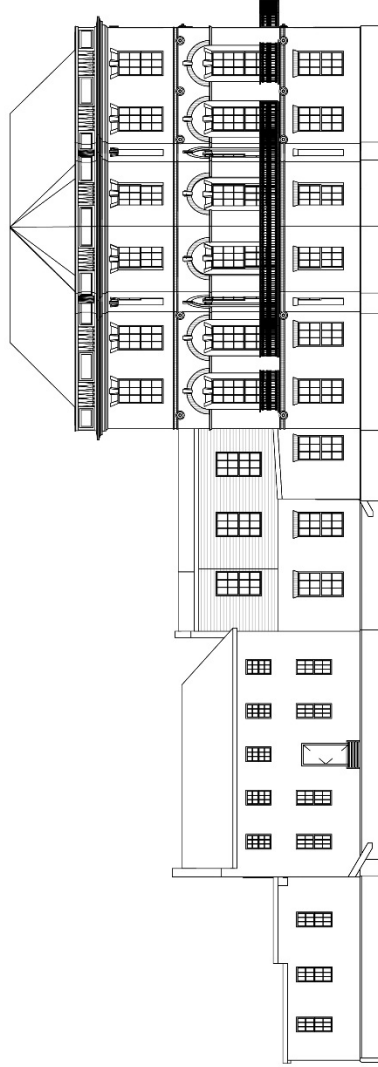
A127



**This drawing was produced in Autodesk Revit with help from information and drawings provided by the Historic Charleston Foundation, Historic Structures Report of the Nathaniel Russell House and through drawings provided by Glenn Keyes Architects and Whole Building Systems.
 Orlando Ridout, V and Willie Graham, An Architectural and Historical Analysis of the Nathaniel Russell House, report, vol. I (Charleston, SC: Historic Charleston Foundation, 1996).

3/12/2015 1:07:14 PM

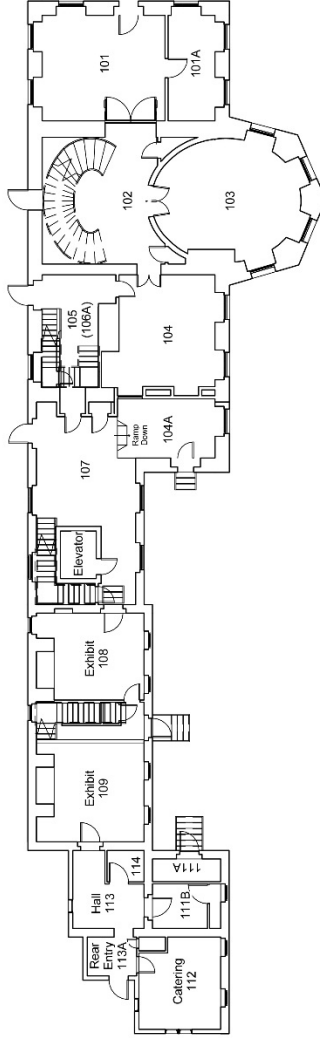
Autodesk® Revit®		Historic Charleston Foundation		PERIOD VI - c. 1956 - Level 3	
www.autodesk.com/revit		Nathaniel Russell House		Project number	NRH03012015
				Date	March 23, 2015
				Drawn by	Laura Lee Worrell
				Checked by	n/a
				Scale	1" = 30'-0"



**This drawing was produced in Autodesk Revit with help from information and drawings provided by the Historic Charleston Foundation, Historic Structures Report of the Nathaniel Russell House and through drawings provided by Glenn Keyes Architects and Whole Building Systems.
 Orlando Ridout, V and Willie Graham, An Architectural and Historical Analysis of the Nathaniel Russell House, report, vol. I (Charleston, SC: Historic Charleston Foundation, 1996).

3/12/2015 1:07:31 PM

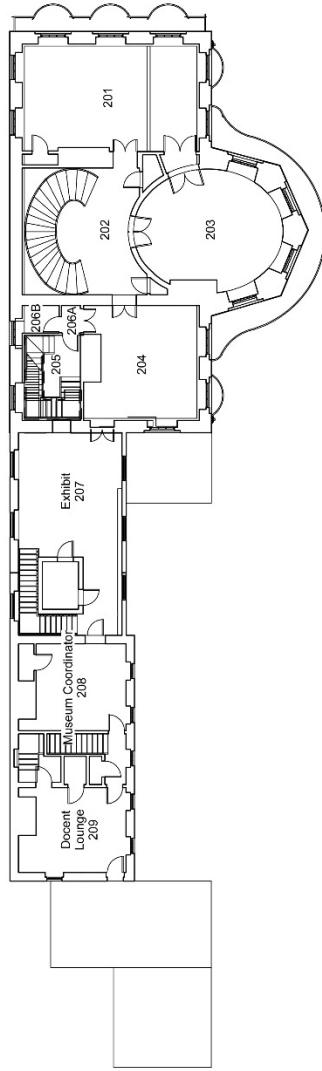
Autodesk® Revit®		Historic Charleston Foundation		PERIOD VII - c. 1912 - South Elevation	
www.autodesk.com/revit		Project number	NRH03012015	A129	
		Date	March 23, 2015		
		Drawn by	Laura Lee Worrell		
		Checked by	n/a	Scale	1" = 30'-0"



3/12/2015 1:07:35 PM

**This drawing was produced in Autodesk Revit with help from information and drawings provided by the Historic Charleston Foundation, Historic Structures Report of the Nathaniel Russell House and through drawings provided by Glenn Keyes Architects and Whole Building Systems.
 Orlando Ridout, V and Willie Graham, An Architectural and Historical Analysis of the Nathaniel Russell House, report, vol. I (Charleston, SC: Historic Charleston Foundation, 1996).

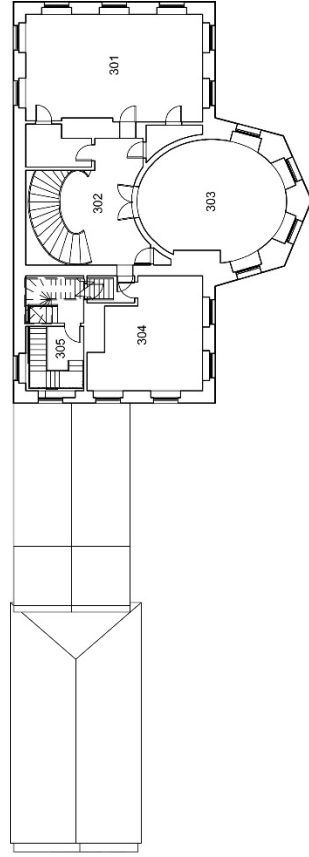
Autodesk® Revit®		Historic Charleston Foundation		PERIOD VII - c. 2012 - Level 1	
www.autodesk.com/revit		Nathaniel Russell House		Project number	NRH03012015
				Date	March 23, 2015
				Drawn by	Laura Lee Worrell
				Checked by	n/a
				Scale	1" = 30'-0"



**This drawing was produced in Autodesk Revit with help from information and drawings provided by the Historic Charleston Foundation, Historic Structures Report of the Nathaniel Russell House and through drawings provided by Glenn Keyes Architects and Whole Building Systems.
 Orlando Ridout, V and Willie Graham, An Architectural and Historical Analysis of the Nathaniel Russell House, report, vol. I (Charleston, SC: Historic Charleston Foundation, 1996).

3/12/2015 1:07:43 PM

Autodesk® Revit®		Historic Charleston Foundation		PERIOD VII - c. 2012 - Level 2	
www.autodesk.com/revit		Nathaniel Russell House		Project number	NRH03012015
				Date	March 23, 2015
				Drawn by	Laura Lee Worrell
				Checked by	n/a
				Scale	1" = 30'-0"



**This drawing was produced in Autodesk Revit with help from information and drawings provided by the Historic Charleston Foundation, Historic Structures Report of the Nathaniel Russell House and through drawings provided by Glenn Keyes Architects and Whole Building Systems.
 Orlando Ridout, V and Willie Graham, An Architectural and Historical Analysis of the Nathaniel Russell House, report, vol. I (Charleston, SC: Historic Charleston Foundation, 1996).

3/12/2015 1:07:48 PM

Autodesk® Revit®	Historic Charleston Foundation		PERIOD VII - c. 1912 - Level 3	
	www.autodesk.com/revit		Project number	NRH03012015
		Nathaniel Russell House	Date	March 23, 2015
			Drawn by	Laura Lee Worrell
			Checked by	n/a
			Scale	1" = 30'-0"

A132

REFERENCES

- Abdel-Bary Ebrahim, Dr. Mostafa. *3D Laser Scanners: History, Applications, and Future*. Civil Engineering Department, Assiut University. Research Gate. October 2011.
http://www.researchgate.net/profile/Mostafa_Ebrahim/publication/267037683_3D_LASER_SCANNERS_HISTORY_APPLICATIONS_AND_FUTURE/links/5442bdf10cf2e6f0c0f93727.pdf.
- Autodesk, Inc. "Company." Autodesk. 2015. Accessed February 22, 2015.
<http://usa.autodesk.com/company/>.
- Autodesk PR. "European Parliament Directive to Spur BIM Adoption in 28 EU Countries." Editorial. *In the Fold*, January 31, 2014.
http://inthefold.autodesk.com/in_the_fold/2014/01/european-parliament-directive-to-spur-bim-adoption-in-28-eu-countries.html.
- Cassidy, Thomas J., Jr., Barbara Pahl, Sharee Williamson, and Elizabeth Merritt. *Historic Leasing in the National Park System: Preserving History Through Effective Partnerships*. Report. Washington D.C.: National Trust for Historic Preservation, 2013.
- Chenaux, A., M. Murphy, G. Keenaghan, J. Jenkins, E. McGovern, and S. Pavia. "Combining a Virtual Learning Tool and Onsite Study Visits of Four Conservation Sites in Europe." Proceedings of XXIII CIPA Symposium. 2011.
<http://arrow.dit.ie/beschconcon/9/>.
- Davidson, Paul, and Dana Lockett. *Assessing the Value of Laser Scan Data*. Proceedings of 3D Digital Documentation Summit, Presidio, San Francisco, CA. 2012.
doi:<http://ncptt.nps.gov/blog/documentation-to-the-secretary-of-the-interiors-standards-assessing-the-value-of-laser-scan-data/>.
- Davidson, Paul, and Daniel De Sousa. "Ellis Island Hospital Building Point Cloud." Laser Scanning. 2014.
- DeWitt, Bon, and Benjamin Wilkinson. "Introduction." In *Elements of Photogrammetry with Application in GIS*, by Paul Wolf. Fourth ed. McGraw-Hill Professional, 2014.
- Dore, C., and M. Murphy. "Integration of HBIM and 3D GIS for Digital Heritage Modelling." 22-23. Proceedings of Digital Documentation, Edinburg, Scotland. 2012. <http://arrow.dit.ie/beschconcon/13/>.

East, Bill, PhD, PE, F.ASCE. *Construction-Operations Building Information Exchange (COBie)*. Report. August 4, 2014. <http://www.wbdg.org/resources/cobie.php>.

Eppich, Rand, and Amel Chabbi. *Recording, Documenting, and Information Management for the Conservation of Heritage Places: Guiding Principles*. Publication. 2007 ed. Los Angeles, CA: Getty Conservation Institute, 2007. http://hdl.handle.net/10020/gci_pubs/recordim_vol2.

European Commission. *DURAARK*. DURAARK, 2015.

FM2589: From Laser Scan to Facilities Management: A Workflow Case Study. Directed by Autodesk University. Performed by Aaron Maller. Classes On Demand. 2012. <http://au.autodesk.com/au-online/classes-on-demand/class-catalog/2012/autodesk-revit-for-architects/from-laser-scan-to-facilities-management-a-workflow-case-study>.

Geographic Information Systems: Challenges to Effective Data Sharing, Subcommittee on Technology, Information Policy, Intergovernmental Relations and the Census, Committee on Government Reform, House of Representatives Cong. (2003) (testimony of Linda D. Koontz).

Georgia O'Keeffe Museum. *Applications of Digital Photogrammetric Methods for Preservation Documentation of Historic Homes*. Report. Natchitoches, LA: National Center for Preservation Technology and Training, 2012.

Lavoie, Catherine C. "The Role of HABS in the Field of Architectural Documentation." *APT Bulletin: Special Issue on Documentation*, 4th ser., 41 (2010): 19-24. <http://www.jstor.org/stable/41000033>.

Mason, Anne. *Archive of Digital Data for HABS, HAER, and HALS*. Proceedings of 3D Digital Documentation Summit, Presidio, San Francisco, CA. April 2012. <http://ncptt.nps.gov/blog/archive-of-digital-data-for-habs-haer-and-hals/>.

McGrath, Gerald, and L. M. Sebert. "Chapter 15." In *Mapping a Northern Land: The Survey of Canada, 1947-1994*. Montreal: McGill-Queen's University Press, 1999.

McGraw-Hill Construction. *The Business Value of BIM in North America: Multi-Year Trend Analysis and User Ratings (2007-2012)*. Report. 2012.

Meeks, Stephanie. "TrustLive: Opening Plenary and Preservation TOMORROW." Past Forward National Preservation Conference, Lucas Theatre, Savannah, GA, November 12, 2014.

- Mount Vernon. "Mount Vernon in 3D: Placing a Historic Building Information Model (HBIM) in Its Landscape." News release, 2015. Digitizing Mount Vernon. <http://www.mountvernon.org/research-collections/preservation/digitizing-mount-vernon/>.
- National Institute of Building Sciences. "About the National BIM Standard-United States™." About the National BIM Standard-United States. 2015. Accessed February 22, 2015. <http://www.nationalbimstandard.org/about.php>.
- National Park Service Northeast Region GIS, and University of Rhode Island Environmental Data Center. *CAD to GIS: A Step-By-Step Guide to Converting.dwg CAD Files to GIS Shapefiles*. Report. Boston, Massachusetts: National Park Service, 2005.
- Poston, Jonathan H. *The Buildings of Charleston: A Guide to the City's Architecture*. Columbia, SC: University of South Carolina Press, 1997.
- Quirk, Vanessa. "A Brief History of BIM / Michael S. Bergin." *Architecture News*, December 07, 2012.
- Ridout, Orlando, V, and Willie Graham. *An Architectural and Historical Analysis of the Nathaniel Russell House*. Report. Vol. I. Charleston, SC: Historic Charleston Foundation, 1996.
- Sapp, Don, and Dan Eckstein. "Computerized Maintenance Management Systems (CMMS)." Computerized Maintenance Management Systems (CMMS). October 23, 2014. Accessed February 22, 2015. <http://www.wbdg.org/om/cmms.php>.
- Schenk, T. *Digital Photogrammetry*. Report. Laurelville,, OH: TerraScience, 1999.
- Skarmeas, George C. "From HABS to BIM: Personal Experiences, Thoughts, and Reflections." *APT Bulletin* 41, no. 4 (2010): 47-53. Accessed September 22, 2014. <http://www.jstor.org/stable/41000038>.
- Slaton, Deborah. "Preservation Brief 43: The Preparation and Use of Historic Structure Reports." National Parks Service. April 2005. Accessed March 03, 2015. <http://www.nps.gov/tps/how-to-preserve/briefs/43-historic-structure-reports.htm>.
- Sprinkle, John H. "An Orderly, Balanced, and Comprehensive Panorama." In *Crafting Preservation Criteria: The National Register of Historic Places and American Historic Preservation*, 26-32. New York, NY: Routledge, 2014.

United States. National Park Service. "Secretary's Standards--Architectural and Engineering Documentation." National Parks Service. Accessed February 24, 2015. http://www.nps.gov/history/local-law/arch_stnds_6.htm.

Wright, Christina, Joe DeVivo, and Kate Funk. *Information Management and Archiving Plan: Southeast Coast Inventory and Monitoring Network*. Report no. NPS/SECN/NRR-2005/062. Fort Collins, Colorado: U.S. Department of the Interior National Park Service, 2008.